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FUNDAMENTALS OF ELECTRONICS

VOLUME 5

OSCILLOSCOPE CIRCUIT APPLICATIONS

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PREFACE

This book is part of a nine-volume set entitled "Fundamentals of Electronics". The nine volumes include:

Volume 1a - NavPers 93400A-1a, Basic Electricity, Direct Current
Volume 1b - NavPers 93400A-1b, Basic Electricity, Alternating Current
Volume 2 - NavPers 93400A-2, Power Supplies and Amplifiers
Volume 3 - NavPers 93400A-3, Transmitter Circuit Applications
Volume 4 - NavPers 93400A-4, Receiver Circuit Applications
Volume 5 - NavPers 93400A-5, Oscilloscope Circuit Applications
Volume 6 - NavPers 93400A-6, Microwave Circuit Applications
Volume 7 - NavPers 93400A-7, Electromagnetic Circuits and Devices
Volume 8 - NavPers 93400A-8, Tables and Master Index

If you are becoming acquainted with electricity or electronics for the first time, study volumes one through seven in their numerical sequence. If you have a background equivalent to the information contained in volumes one and two, you are prepared to study the material contained in any of the remaining volumes. A master index for all volumes is included in volume eight. Volume eight also contains technical and mathematical tables that are useful in the study of the other volumes.

A question (or questions) follows each group of paragraphs. The questions are designed to determine if you understand the immediately preceding information. As you study, write out your answers to each question on a sheet of paper. If you have difficulty in phrasing an answer, restudy the applicable paragraphs. Do not advance to the next block of paragraphs until you are satisfied that you have written a correct answer.

When you have completed study of the text matter and written satisfactory answers to all questions on two facing pages of the book, compare your answers with those at the top of the next even-numbered page. If the answers match, you may continue your study with reasonable assurance that you have understood and can apply the material you have studied. Whenever your answers are incorrect, restudy the applicable material to determine why the book answer is correct and yours is not. If you make an honest effort to follow these instructions, you will have achieved the maximum learning benefits from each study assignment.

Follow the directions of your instructor in answering the review questions included at the end of each chapter.

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CHAPTER 41

CATHODE RAY TUBE

The following paragraphs introduce the OSCILLOSCOPE and the function of the oscilloscopes major components. A full description of the major components of the oscilloscope will be given in subsequent chapters.

41-1. Use of Oscilloscopes

The oscilloscope is designed for use as a test instrument. It is capable of visually displaying the results of any number of tests on an electronically excited screen.

Among the oscilloscopes many practical applications are the following: alignment of radio and radar receiving and transmitting equipment, hum measurement, frequency comparison, waveform observation, percentage of modulation, and many other similar applications. A block diagram of the oscilloscope is shown in Figure 41-1.

41-2. Power Supply Requirements

The power supply of an oscilloscope must provide a filtered low to medium B+ potential as required by the individual tube circuits, and a high value of B+ for the cathode ray tube. These power supplies are respectively termed the low voltage (LV) power supply and the high voltage (HV) power supply. The LV supply, normally ranging from 100 to 500 volts, is a high current supply, and the HV supply, ranging from approximately 1000 to 5000 volts, is a low current supply.

41-3. Cathode-Ray Tube Circuit

The CATHODE-RAY TUBE CIRCUIT consists of a cathode-ray tube (CRT) and its related controls, the INTENSITY CONTROL and the FOCUS CONTROL. The CRT is the visual display device of the oscilloscope. The CRT operates in the following manner: a beam of electrons leaves the cathode of the tube, is accelerated through the tube, and strikes a phosphor coated screen which glows at the point of impact. This beam is focused to a sharp point by the action of the focus control. The brightness (or intensity) of the beam is controlled by the intensity control. The beam sweeps the screen in the horizontal and vertical directions when the appropriate voltages are applied to the HORIZONTAL and VERTICAL DEFLECTION PLATES. The resultant trace left by the beam is a visual presentation of a voltage waveform in the circuit being examined.

41-4. Vertical Deflection Amplifier Circuit

The voltage waveform to be examined may be applied directly to the vertical deflection plates of the CRT. In most cases, however, the voltage to be presented is either too small or too large in amplitude to be examined. It must be either amplified or attenuated. The amplification or attenuation of the input to the vertical deflection plates is accomplished by the VERTICAL DEFLECTION AMPLIFIER CIRCUIT.

If a voltage is applied to the vertical deflection plates without a voltage applied to the horizontal deflection plates, only a thin vertical line will appear at the face of the scope.

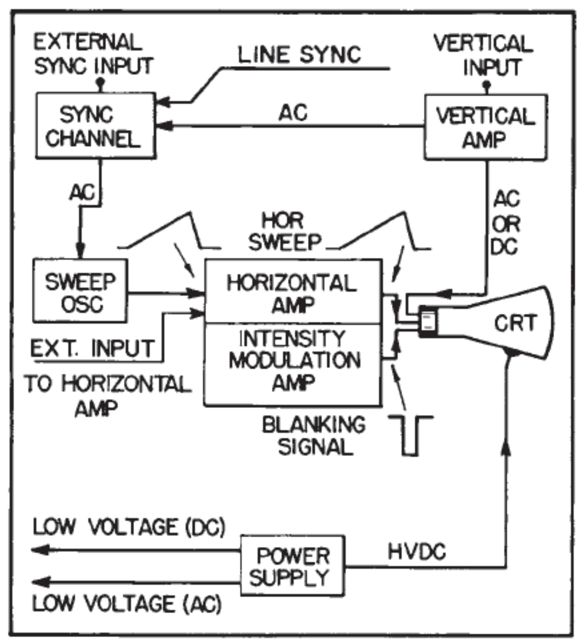

Figure 41-1 - Block diagram of the basic oscilloscope.

41-5. Horizontal Deflection Amplifier

The purpose of the HORIZONTAL DEFLECTION AMPLIFIER is to establish the desired

amplitude of sweep voltages applied to the horizontal deflection plates of the CRT. The sweep voltage will control the beam deflection across the face of the CRT. The input to the horizontal amplifier may be selected from the SWEEP OSCILLATOR in Figure 41-1, or from some external source.

If the screen of the CRT is observed without a vertical signal applied, only a horizontal line would be present on the face of the CRT. The length of the horizontal line is dependent upon the amplitude of the sweep voltage applied to the horizontal deflection plates. The amplitude of the sweep voltage applied to the horizontal deflection plates is controlled by the HORIZONTAL GAIN CONTROL.

41-6. Sweep Circuit Oscillator

The SWEEP CIRCUIT OSCILLATOR provides a voltage which is applied to the input of the horizontal amplifier. In order for the time base across the face of the CRT to be linear, thus preventing a distorted signal on the screen, the rise of voltage of the sweep circuit, which is a sawtooth generator, must be linear with respect to time. The decay time of the sawtooth waveform must fall or return to its original value as rapidly as possible. This must be done to assure that the electron beam returns to the left side of the scope as rapidly as possible. If this were not done, a portion of the signal under observation would not be seen.

41-7. Sweep Synchronizing Circuit

The type of sweep circuit normally used in an oscilloscope is a free-running sawtooth generator. This type of circuit is not a particularly stable type. To observe a signal on the face of the scope, the sweep frequency and the frequency of the signal to be observed must be synchronized. In order to achieve synchronization of the sweep oscillator with the frequency under observation, a synchronizing signal must be obtained from the signal under observation and applied to the sweep circuit. This operation will insure that the sweep will always start at the same position in the observed cycle. The synchronizing signal may also be obtained from the line frequency or some outside source.

41-8. Intensity Modulation Amplifier Circuit

In most oscilloscopes, there is a separate amplifier known as the INTENSITY MODULATION AMPLIFIER. When the circuit is operating, either a positive or negative signal is obtained from it and fed to the cathode or control grid to vary the bias on the CRT. This will change the density of the electron beam, thereby changing the intensity of the trace. The most common use of this circuit is to take a signal from the sweep oscillator having the exact time duration as the retrace time of the sweep, amplify it, and use it to bias the CRT to cut-off during the time for retrace. This action is known as BLANKING.

CATHODE-RAY TUBE

The CATHODE-RAY TUBE (CRT) is a special type of vacuum tube in which a beam of electrons is made to strike a phosphor coated screen and produce light. By moving the beam over the phosphor screen, patterns of light are produced which are a visual representation of the voltages used to move the beam. Thus, the electron beam can be used to trace pictures of the voltage waveform existing at some point in a circuit.

When the cathode-ray tube is used to analyze voltage waveforms, the cathode-ray tube and its supporting circuitry are called an oscilloscope. As a test instrument, the oscilloscope is a device whose versatility is limited only by the skill of the operator. Whereas the voltmeter is capable of little more than amplitude measurement, the oscilloscope can be used to measure current and voltage amplitude, frequency, phase, and time, in addition to permitting the operator to actually see the waveform under test. Distortion in a waveform is generally not apparent from a voltmeter measurement, but can be quickly recognized from the pattern traced out on the screen of the CRT.

Since the electron beam is nearly weightless the beam can be deflected almost instantaneously, permitting the observation of high frequencies, or pulse waveforms of nanosecond duration. The ability of the cathode-ray tube to measure minute intervals of time makes it an ideal device for the display and measurement of the information obtained from radar and sonar systems. With the addition of intensity modulation the cathode-ray tube becomes capable of displaying moving pictures, hence, the miracle of television.

41-9. CRT Construction

The envelope of a cathode-ray tube consists of a large glass bell with a long cylindrical glass tube called the "neck." As shown in Figure 41-2, the phosphor screen is deposited on the inside of a glass faceplate covering the end of the bell. The electrodes which form the electron beam comprise an assembly called the ELECTRON GUN. The electron gun assembly is placed in the neck of the tube and connects through internal leads to the pins on the base. The beam is moved either

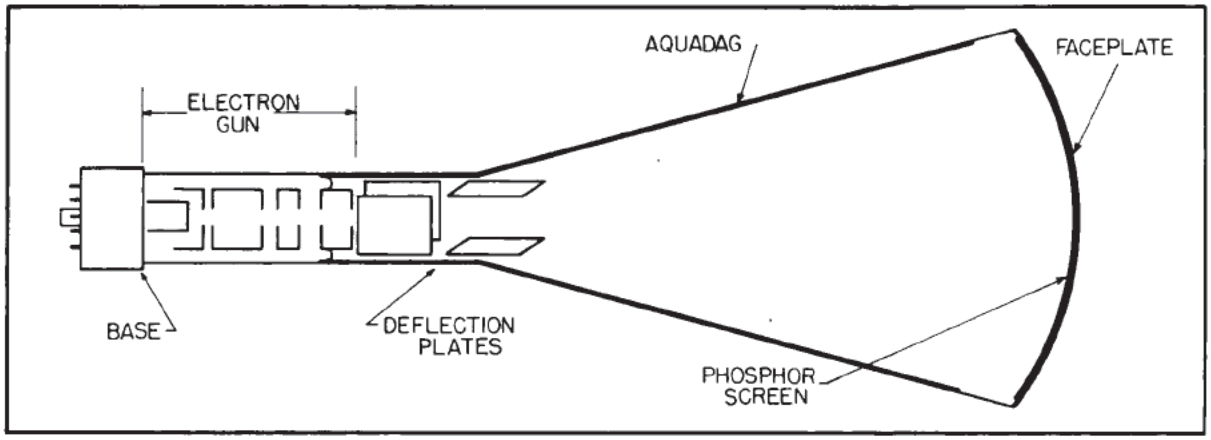

Figure 41-2 - Cathode-ray tube assembly.

horizontally or vertically by two pairs of DEFLECTION PLATES between which the beam must pass on its way to the screen. These plates are mounted on, but not part of, the electron gun. In some types of cathode-ray tubes the beam is deflected magnetically by a coil placed around the neck of the tube. The magnetically deflected CRT does not use deflection plates. Thus, cathode-ray tubes are classified as either ELECTROSTATIC or ELECTROMAGNETIC depending on the method used to deflect the beam.

The inside of the bell of a cathode-ray tube is covered with a conductive graphite coating. This coating, called AQUADAG, provides shielding from stray fields which might interfere with the electron beam, prevents light from striking the back of the screen and most important, gathers the secondary electrons emitted when the phosphor is bombarded by the electron stream, returning them to the cathode through the accelerating anode power supply.

Once the electron beam is formed by the gun assembly, it must travel from several inches to one foot or more, before reaching the screen. Since even a small number of collisions between the electron beam and air molecules would adversely affect the operation of the cathode-ray tube, the tube must be highly evacuated. The high degree of evacuation and large surface area of the tube makes the tube especially vulnerable to dangerous implosions of tremendous force. In many cases, sudden jarring, or slight nicks or scratches in the glass are sufficient to cause an implosion. Great care should be exercised when handling cathode-ray tubes, and their installation or removal should not be attempted without the protection of safety goggles and heavy gloves. When servicing equipment containing cathode-ray tubes, care should be taken that the tube is not bumped or scratched by tools.

In the following topics, each part of the CRT will be described separately.

41-10. Phosphor Screen

The function of the phosphor screen is the conversion of the kinetic energy of the beam electrons into light (radiant energy). As one of the beam electrons strikes a phosphor atom the energy of the beam electron is transferred to one of the planetary electrons of the phosphor atom. This causes the electron in the phosphor atom to jump to a higher energy orbit farther from the nucleus. As the atom is thus placed in an unnatural or EXCITED state, the electron will try to give up the excess energy and return to its normal orbit. In returning, the electron releases its excess energy in the form of radiant energy.

The wavelengths of the energy quanta emitted by the phosphor atoms extend from the ultraviolet, through the visable spectrum, to the infra-red. Thus, both light and heat energy are given off by the screen. Should the energy of the beam electrons be too great, the heat developed within the phosphor can alter its chemical characteristics causing a burned spot on the screen. Once burned, the screen is permanently damaged and will no longer produce light over the area of the burn. When using a CRT, the intensity of the beam should never be greater than that required to produce a usable amount of light on the screen.

The characteristics of the phosphor depend on its chemical composition. Phosphors are composed of compounds of zinc, magnesium, and cadmium to which is added small traces of certain other chemicals called "activators." The activator increases the light output of the basic phosphor compounds.

Phosphor screens are classified according to the color of the light produced and the length of time during which the light is given off. The

COATING	APPLICATION	PERSISTENCE	DECAY TIME (sec)	FLUORESCENCE	PHOSPHORESCENCE
P1	General Oscilloscope	Medium	0.03	Green	Green
P4	Television	Medium	0.06	White	White
P5	High Speed Photography	Very short	35×10^{-6}	Blue	Blue
P7	Radar, sonar	Long	3	Blue-White	Greenish-Yellow

Table 41-1 - Characteristics of cathode-ray tube phosphors

length of time required for the light to decay to one percent of its maximum value after the excitation has been removed is called the PERSISTENCY of the phosphor.

If the persistency of the screen material is about 0.01 second or less, the tube is said to have a short persistency. Tubes with persistency values longer than one second are designated as long persistency types. If the duration of the glow is between these two values, the persistency is medium.

The emission of light at a temperature below that of incandescent bodies is called LUMINESCENCE (cold light). If light is given off during excitation of the phosphor, the process is called FLUORESCENCE. The emission of light which occurs after excitation has ceased (afterglow) is called PHOSPHORESCENCE.

TABLE 41-1 lists some of the more popular screen coatings and their characteristics. Notice, that the various types of coatings are cataloged by letter-number designations such as P1, P4, etc. For example, a P1 phosphor has a medium persistency of 0.03 seconds and has green fluorescence and phosphorescence. In some types of coatings fluorescence is of a different color than phosphorescence.

Q1. List two factors which would determine the amount of light obtained from the screen.

41-11. Electron Gun Assembly

Depending on the application for which the tube was designed, the electron gun consists of from four to six cylindrically shaped electrodes placed end-to-end within the neck of the tube. The gun structure to be discussed in the following paragraphs is the one used in the 5UP1. This tube was designed for general oscillographic applications and has a tetrode type gun structure. The tube number (5UP1) indicates that the tube has a five inch diameter screen and a P1 phosphor.

The arrangement of electrodes in the gun, and the tube base connections are shown in Figure 41-3. Since the gun assembly must form the electrons into a pencil-like beam, the electrodes are fabricated in the shape of cylinders. To aid in confining the electron stream to a thin beam, several disc-shaped baffle plates or diaphragms containing small holes at their centers are placed within the various cylinders. These baffle plates screen out all but those electrons travelling close to the longitudinal axis of the gun.

The emitter of a cathode-ray tube is indirectly heated and is made in the shape of a cylinder with a flat closed end. The emission occurs only from the flat end of the nickel cylinder which is coated with barium and strontium oxides to enhance the emission. The emitting material is maintained at the proper temperature by a tungsten heater placed inside the nickel cathode cylinder. To prevent the twisted heater wire from shorting to the cathode, the heater is surrounded by a heat-conducting ceramic sleeve. In certain applications the cathode is directly connected to the filaments to prevent a high intensity field between the two elements.

As shown in Figure 41-3, the cathode is almost completely enclosed by the control grid cylinder. This cylinder has a small hole in the center of the flat end, through which electrons can pass on their way to the screen.

When the proper operating potentials are applied to the tube, the preaccelerating anode is from one to two thousand volts positive with respect to the cathode. This difference of potential causes lines of force to extend from the preaccelerating anode, through the hole in the control grid, to the space charge surrounding the end of the cathode. These lines of force cause some of the space charge electrons to be drawn through the hole in the control grid and accelerated down the length of the tube.

The control grid is operated at a bias potential of from 0 to -90 volts. As the control grid is made increasingly negative, fewer electrons are able to pass through the hole in the grid and the electron density of the beam is decreased. This

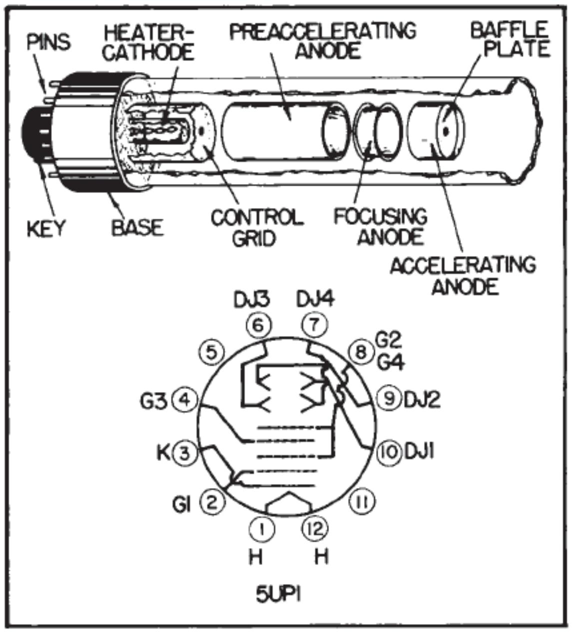

Figure 41-3 - Electron gun structure and tube base diagram.

in turn decreases the amount of light produced on the screen. If the control grid potential is adjusted to approximately -90 volts, electron flow through the grid is entirely stopped and no light is produced on the screen.

By connecting a potentiometer between the control grid and cathode, the negative grid bias can be adjusted to provide the proper amount of light on the screen. This potentiometer is mounted on the front panel of the oscilloscope and is called the BRIGHTNESS or INTENSITY control.

The preaccelerating anode, sometimes referred to as the preaccelerating grid, is followed by the focus and accelerating anodes respectively. In order to display intricate waveforms without masking fine detail, the beam must be focused to a very small diameter spot by the time it reaches the screen. Focusing of the beam is accomplished by the electrostatic field existing between the focus anode and the preaccelerating and accelerating anodes.

To illustrate focusing action, the field between the focus anode and the second or accelerating anode is shown in Figure 41-4. (A similar action occurs between the focus and preaccelerating anodes.) The electrons which succeed in passing through the control grid and preaccelerating anode come under the influence of the focus anode.

Some of the electrons pass through the hole in the end of the focus anode and into the field between the focus and accelerating anodes. The purpose of the diaphragm is to prevent all electrons, except those making a small angle with the axis of the beam, from passing through the hole in the diaphragm. This serves to keep the beam narrow. The electrons entering the curved electric field between the anodes are subjected to inward-directed forces thereby focusing the beam. As the beam passes parallel to the lines of force, the electrons are accelerated to a very high speed. Thus, the net result of the forces influencing the beam of electrons is a high speed inward-directed beam converging at point S on the screen. The repelling force of like charges in the beam tends to scatter the electrons but they are accelerated to such a high speed that the scattering action is not effective in defocusing the beam. Nevertheless the mutul repulsion between electrons in relation to the speed of the electrons determines the sharpness with which a beam may be focused on the screen. The diaphragm on the accelerating anode is used to stop all wide angle electrons from hitting the screen.

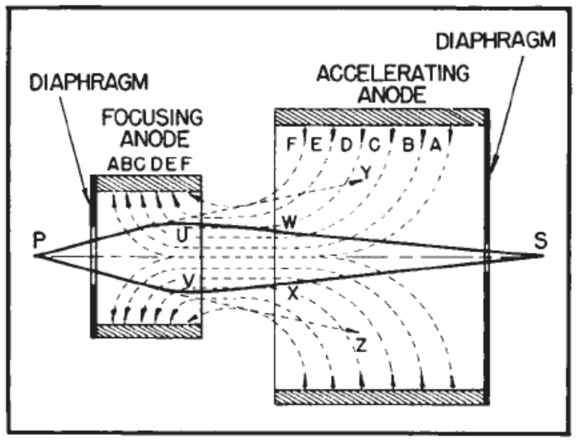

Figure 41-4 - Electrostatic focusing.

In most cathode-ray tubes the preaccelerating and accelerating anodes are connected together internally and therefore operate at the same potential. At an accelerating anode potential of 1000 volts, the focus anode of the 5UP1 should operate at +170 to +320 volts dc.

By varying the potential on the focus anode with respect to the fixed potential on the accelerating anodes, the focus of the beam can be controlled. If the potential difference between the focus and accelerating anodes is increased, a stronger electrostatic field results and the focal point (point S) moves toward the gun. The potential on the focus anode should be adjusted until the beam forms a bright sharp spot on the screen. This voltage adjustment is accomplished with a front panel potentiometer called the FOCUS control.

A1. (1) The number of electrons striking the screen.
(2) The velocity (energy) of each electron.

Q2. If the potential on the focus anode was made equal to the potential on the accelerating anode, what change in the spot of light on the screen would be observed?

ELECTROSTATIC DEFLECTION

In order to trace out a waveform on the fluorescent screen, the beam must be made to move in conformity with a voltage or current. As the beam consists of moving negative charges it is surrounded by both a magnetic field and an electric field. If by some external means, either a magnetic or an electrostatic field is established in the vicinity of the beam, forces will be brought to bear on the beam causing it to shift position. If the movement is to be produced by magnetic means, a coil is placed about the neck of the CRT. As the beam electrons leave the electron gun they pass through the magnetic field set up by the coil. When the coil field and the magnetic field about the beam electrons interact, the beam is deflected away from its normal position. The amount and direction of beam deflection is determined by the magnitude and direction of the current passed through the deflection coil.

Since nearly all cathode-ray tubes designed for use in oscilloscopes use electrostatic deflection, electromagnetic deflection principles will not be discussed at this time.

41-12. Deflection Plates

Electrostatic deflection is accomplished by routing the electron beam between two parallel metal plates to which the deflection voltage is applied. If two parallel plates are positioned near the end of the electron gun assembly, as shown in Figure 41-5, the beam can be made to strike the screen at any point along a vertical line passing through the center of the screen.

When no difference of potential exists between the deflection plates the beam will be unaffected and pass directly down the center of the tube and strike the screen at point A. If a difference of potential is applied to the plates, the area between the plates will be filled with lines of force. Assuming the top plate to be positive with respect to the bottom plate, an electron existing in the space between the plates would be attracted by the top plate and repelled by the bottom plate. Thus, an upward motion would be imparted to the electron by the electrostatic forces between the plates.

Since the electron beam is located between the plates, each electron it contains is acted upon by the force of the electrostatic field. The beam electrons are therefore compelled to follow an upward curving path during the time they are within the influence of the plates. After leaving the vicinity of the plates the electrons travel in a straight line, striking the screen at point B.

If the amount of voltage between the two deflection plates is increased the angle of deflection will increase causing the beam to strike the screen farther from the center. Any amount of upward deflection can be obtained by applying the proper amount of voltage to the plates.

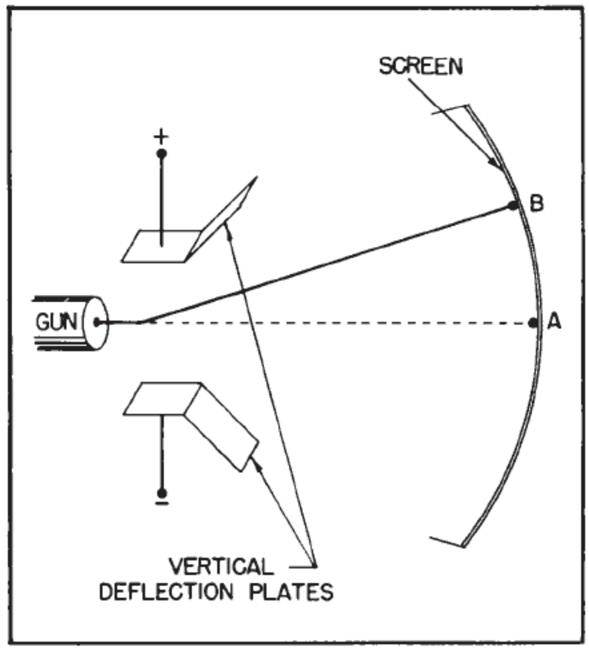

Figure 41-5 - Vertical deflection plates.

To deflect the beam downward from the center of the screen the polarity of the voltage applied to the deflection plates must be reversed. The upper plate will then repel the beam and the lower plate will attract it. As before, the amount of deflection is proportional to the magnitude of the voltage applied to the plates.

Horizontal deflection of the beam is accomplished by placing a second pair of deflection plates just beyond the vertical plates, so that the beam passes through the two pairs of plates in succession, as shown in Figure 41-6. The pair of plates which controls the movement of the beam in a horizontal plane are called the horizontal deflection plates. These plates are mounted perpendicular to the plane of deflection. If voltages are applied simultaneously to both pairs of plates the beam can be moved to any point on the screen.

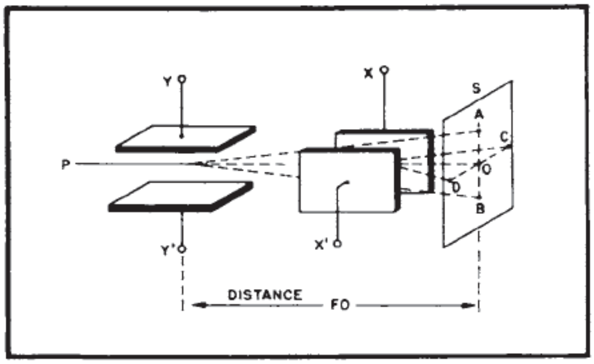

Figure 41-6 - Deflecting plates for electrostatic cathode-ray tube.

Q3. If the bottom vertical deflection plate is at ground potential, what polarity must be applied to the top vertical deflection plate to cause the beam to move down?

41-13. Deflection Sensitivity and Factor

Deflection sensitivity of a cathode-ray tube is a constant which indicates how much the spot on the screen is deflected (in inches, centimeters, or millimeters) for each volt difference of potential that is applied to the deflection plates. For example, tube specifications may describe a certain tube as having a deflection sensitivity of 0.2 millimeter per volt dc. This means that when the tube is operated according to the stipulated conditions, every volt of dc applied to the deflection plates causes the spot to move 0.2 millimeter from its undeflected position. Deflection sensitivity is directly proportional to the length of the deflection plates and the distance between the deflection plates and the screen. It is inversely proportional to the separation between the deflection plate and the accelerating voltage.

Deflection factor indicates the voltage required on the deflection plates to produce a unit deflection on the screen, and it is the reciprocal of deflection sensitivity. It is expressed in terms of a certain number of dc volts per centimeter (or per inch) of spot movement. For example, in the tube mentioned above as having a deflection sensitivity of 0.2 millimeter per volt dc, the deflection factor is 50 volts per centimeter. It is also common to express the deflection factor in terms of the second anode voltage. That is, the deflection factor is given as a certain amount for each kilovolt of second anode voltage that is used—for example, 60 volts dc per inch/kilovolt of second anode voltage indicates that with 1 kilovolt applied to the second anode, the factor is 60 volts per inch. With 2 kilovolts applied to the second anode, the factor is 120 volts per inch.

41-14. Waveform Display

The eye retains an image for about one sixteenth of a second. Thus in a motion picture, the illusion of motion is created by a series of still pictures flashed on the screen so rapidly that the eye cannot follow them as separate pictures. In the cathode-ray tube the beam is repeatedly swept across the screen and the series of adjacent spots appear as a continuous line. Thus, the wave shape of an ac voltage can be observed on the screen when the ac voltage is applied to one pair of deflection plates and simultaneously a second voltage of appropriate characteristics is applied to the other pair of plates.

The sweep voltage that will produce uniform motion of the spot across the screen is called a sawtooth voltage, because the shape of the voltage waveform resembles the cutting edge of a saw. A sawtooth voltage wave is shown in Figure 41-7. The voltage is made to rise from point A along a straight line to point B. This is known as a linear rise. If this voltage is applied to the horizontal deflecting plates of a cathode-ray tube, the spot will move across the screen to form the time base. The time base will be linear with time if a rise of Δ E volts take place in Δt seconds anywhere along AB, since that will mean that the spot moves from S_1 to S_2 (Figure 41-7) in exactly the same time that it moves from S_3 to S_4. Thus, the sweep is a means of measuring time, since it always takes t_1 seconds to go from A to S_1, or t_4 seconds to go from A to S_4.

It is desirable that the time base start at the left of the tube, since that is the more usual method of plotting waveforms. The beam is swept from left to right to produce the pattern, and must be returned quickly to the starting point to restart the pattern. The beam can be returned quickly only if the voltage falls from B to A' (Figure 41-7) very rapidly. In practice,

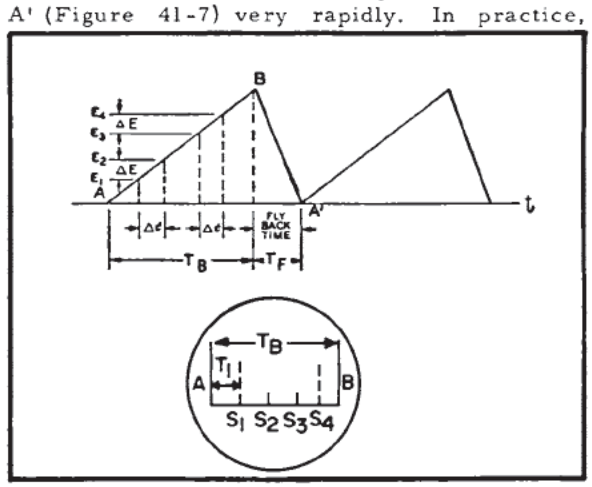

Figure 41-7 - Sawtooth voltage waveform.

A2. Due to the loss of the electrostatic field between the focus and accelerating anodes, the beam would spread out producing a faint and severely defocused disc of light.

A3. A negative potential.

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time T_F is very small compared to the length of the time base T_B. The time T_F is called the FLY-BACK TIME, since it represents the time during which the beam is being moved back to the starting point. Because the fly-back time is so very short, the electron beam is swept over the screen too fast to cause emission of much light, and the return trace is accordingly very dim. The fly-back time is greatly exaggerated in Figure 41-7. If the picture were drawn to scale, the time T_F would appear to be almost zero, and the line BA' almost vertical.

If a test voltage from a circuit, such as the sine wave in Figure 41-8, is applied to the vertical deflection plates, and the sawtooth sweep voltage is applied to the horizontal deflection plates, the resulting screen pattern will be as shown in Figure 41-8. As the sawtooth of voltage moves the beam from left to right at a constant rate of speed, the sine wave to be observed deflects the beam vertically. Thus, the sine wave is reproduced on the screen.

Q4. What waveform would be observed if a square wave was applied to the vertical plates and a sawtooth to the horizontal plates?

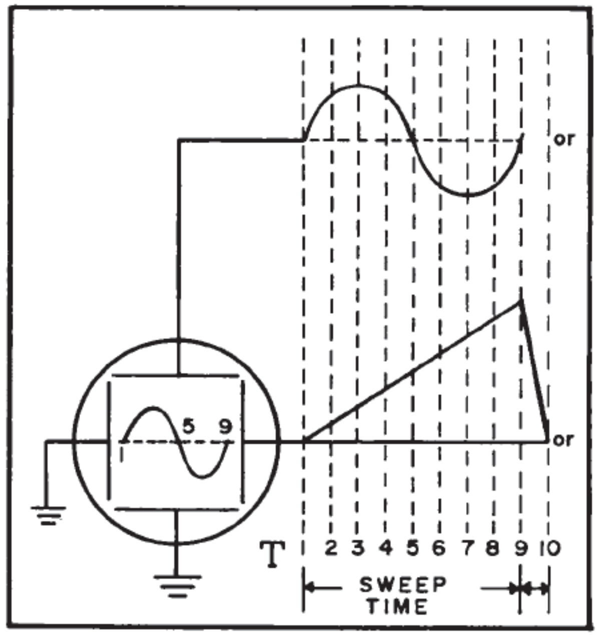

Figure 41-8 - Development of screen pattern.

EXERCISE 41

1. What is an electrostatic field; an electromagnetic field?
2. What is the direction of the electrostatic lines of force?
3. The velocity of an electron in an electrostatic field is determined by what factors?
4. Explain the action of electron beam focusing in the electrostatic type CRT.
5. What direction will an electron beam be deflected in an electrostatic field?
6. Distinguish between the terms phosphorescence and fluorescence as applied to cathode-ray tube screens.
7. Why are cathode-ray tubes dangerous to handle?
8. Distinguish between deflection factor and deflection sensitivity.
9. A two volt signal deflects the beam a total of 0.25 inches. What is the deflection factor?
10. Explain how it is possible to move the spot on the screen in any direction by applying two forces operating at right angles.

A4. A square wave.

CHAPTER 42

OSCILLOSCOPE POWER SUPPLIES

The power supply has as one of its purposes the conversion of alternating current into direct current. In the oscilloscope, the power supply must provide several different values of dc and ac voltages. Direct voltages ranging from 100 to 400 volts must be supplied to the plate and screen circuits of amplifiers. High dc voltages of from - 500 to - 1500 volts, and in some cases up to 15KV, must be provided for proper operation of the cathode ray tube. Low ac voltages must be supplied for tube heaters.

This chapter will deal with a typical oscilloscope power supply. Transformer and rectifier action will be reviewed, and selenium rectifiers will be discussed. It should be noted that the circuits studied in this chapter are similar to those studied in Chapter 16.

42-1. Types of Rectifiers Used

The type of rectifier used in a power supply circuit will depend on the voltage and current requirements of the load. Generally, vacuum diode circuits are used to provide moderate to low dc voltages with relatively high current capabilities; or high dc voltages with light load currents. Both full-wave and half-wave circuits may be used. The selenium metallic rectifier may often be used in place of the vacuum diode.

The SELENIUM RECTIFIER is a semiconductor device which, like the vacuum diode, will normally allow only unidirectional current flow. The physical construction of a SELENIUM CELL is illustrated in Figure 42-1A.

The FORWARD RESISTANCE (from COUNTER ELECTRODE, through the selenium layer, to the aluminum plate) is low, while the BACK RESISTANCE is high. This property allows much greater current flow in the forward direction, essentially making this a unidirectional device. However, an inverse voltage applied to this device will cause a small REVERSE CURRENT to flow. The magnitude of the reverse current will be dependent on the amplitude of the inverse voltage. A PIV (peak inverse voltage) rating is assigned to these units to prevent excessive reverse current. If the PIV rating is exceeded, the resultant heat due to reverse current can render the device useless as a rectifier. Selenium cells generally have a PIV rating of 26v rms per cell. If a higher PIV is

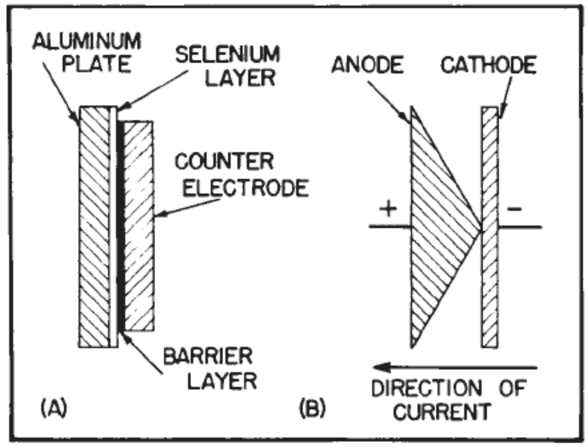

Figure 42-1 - (A) Selenium cell construction.
(B) Schematic symbol.

desired, it can be obtained by "stacking" additional cells in series.

Current carrying capabilities in the forward direction are limited mainly by cross sectional area and operating temperature. The maximum operating temperature of selenium rectifiers is about 55°C (131°F). Operation at higher temperatures will shorten the rectifier's life considerably. Current capabilities can be increased by connecting the cells in parallel. This effectively increases the cross sectional area.

Selenium rectifiers may be used to replace vacuum diodes in many applications. They may be connected as standard half-wave, full-wave, or bridge rectifiers. Selenium rectifiers have the advantages of low cost, light weight, physical durability, and lower input power requirements due to the absence of a heater. The main disadvantage is the reverse current which flows when an inverse voltage is applied. This disadvantage can be controlled by insuring that the PIV rating of the rectifier exceeds the peak voltage appearing in the circuit.

42-2. Block Diagram of Power Supply

A block diagram of the oscilloscope power supply, used in the OS-8C/V, is illustrated in Figure 42-2. Note that several rectifier circuits, supplying different voltages, are located in the same unit.

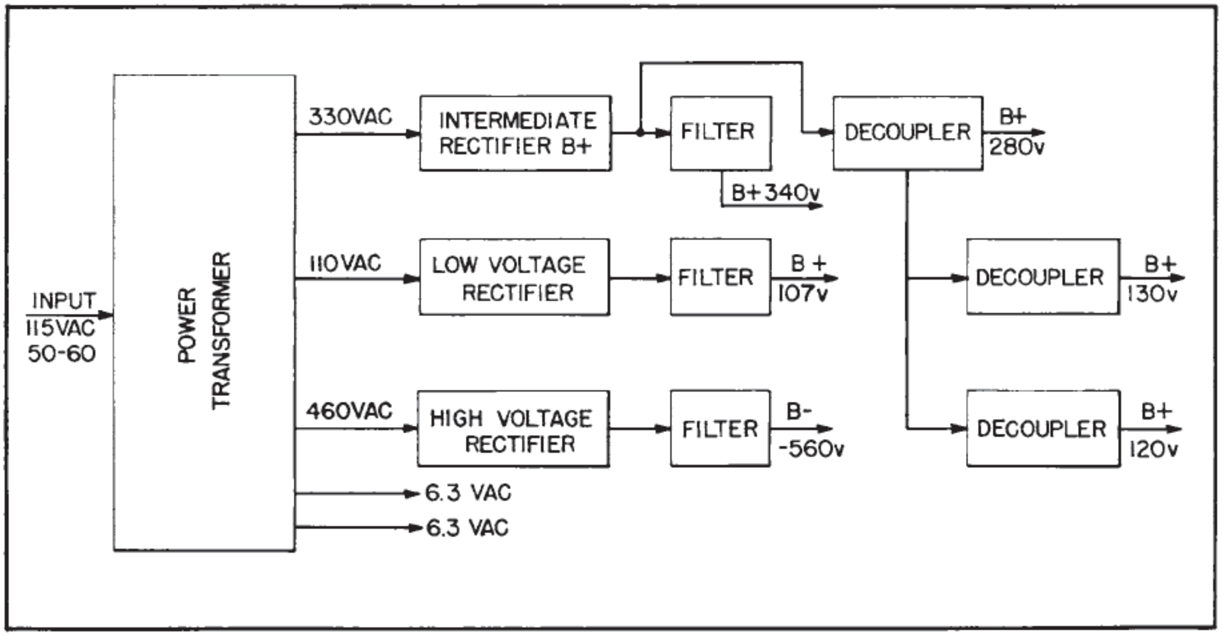

Figure 42-2 OS8C/U power supply - block diagram.

The power transformer has a primary input voltage of 115 vac. The high voltage secondary provides three outputs: 330 vac which is applied to a full-wave rectifier circuit which supplies intermediate values of B+, 110 vac which is applied to a full-wave rectifier for supplying a low B+ value, and 460 vac which is applied to a half-wave rectifier which supplies a high B minus voltage.

Two separate low voltage secondary windings supply 6. 3 vac for tube heater operation. One winding supplies the CRT's heater; the other supplies the amplifier and rectifier tube heaters.

42-3. The Power Transformer

The power transformer in this power supply must provide three high voltage outputs as illustrated in Figure 42-2. One method of supplying these outputs is through the use of separate secondary windings. This method, however, introduces difficulties in construction and results in high cost. A more efficient method of providing these voltages is through the use of a tapped secondary. This method is illustrated in Figure 42-3. The following discussion of secondary voltages will be with reference to Figure 42-3. All secondary voltages are taken with respect to point G, the grounded secondary tap.

Points B to G and points C to G each provide an output of 110 vac. The secondary section, consisting of terminals B-G-C, acts as a 220 volt center tapped winding.

The voltage from point A to B and C to D is 220 vac. The voltage appearing from point A to G, or D to G is then equal to 220 + 110 vac or 330 vac. The secondary section consisting of terminals A-G-D acts as a 660 volt center tapped winding.

The voltage from point D to E is 130 vac. The voltage appearing from point E to G is then equal to 130v + 220v + 110v or 460 vac. The secondary section consisting of terminals E-G acts as a 460v secondary winding.

It can easily be seen that by using taps, the single secondary winding can produce the same outputs as three separate secondaries.

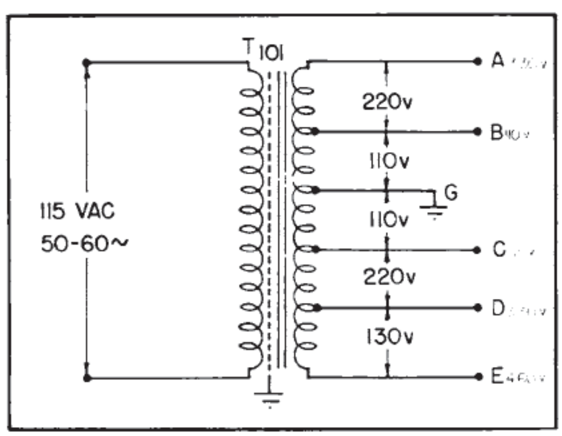

Figure 42-3 - OS8C/U power transformer with tapped secondary.

POWER SUPPLY ANALYSIS

The power supply can be divided into three rectifier sections: the intermediate voltage B+ supply, the low voltage B+ supply, and the high voltage B- supply.

42-4. The Intermediate B+ Supply

The intermediate voltage section is illustrated in Figure 42-4. It consists of the 660 volt center-tapped section of T_{101}, full-wave rectifier V_{110}, and a Pi-section filter. (A complete analysis of rectifiers and filter circuits may be found in Chapters 16 and 17.) V_{110} operates as a conventional full-wave rectifier. The output of V_{110} is applied to a Pi-section filter, which consists of R_{171}, C_{135A}, and C_{135B}. A filtered output of +340 vdc is taken across C_{135B} to provide plate voltage for the horizontal output section.

The output of V_{110} is also applied to a decoupling network which consists of R_{172}, R_{173}, and C_{135C}. This circuit provides additional filtering as well as plate decoupling. An output of +280 vdc is taken across C_{135C} and applied to several circuits. This output provides plate voltage for the vertical output section and positive grid potentials for the CRT. This output is also applied to two decoupling networks. One decoupling network consists of R_{174} and C_{134C}. An output of +120 vdc is taken across C_{134C} to provide plate voltage for the horizontal cathode follower. The other decoupling network consists of R_{175} and C_{134D}. An output of +130 vdc is taken across C_{134D} to provide plate voltage for the vertical cathode follower and sync amplifier.

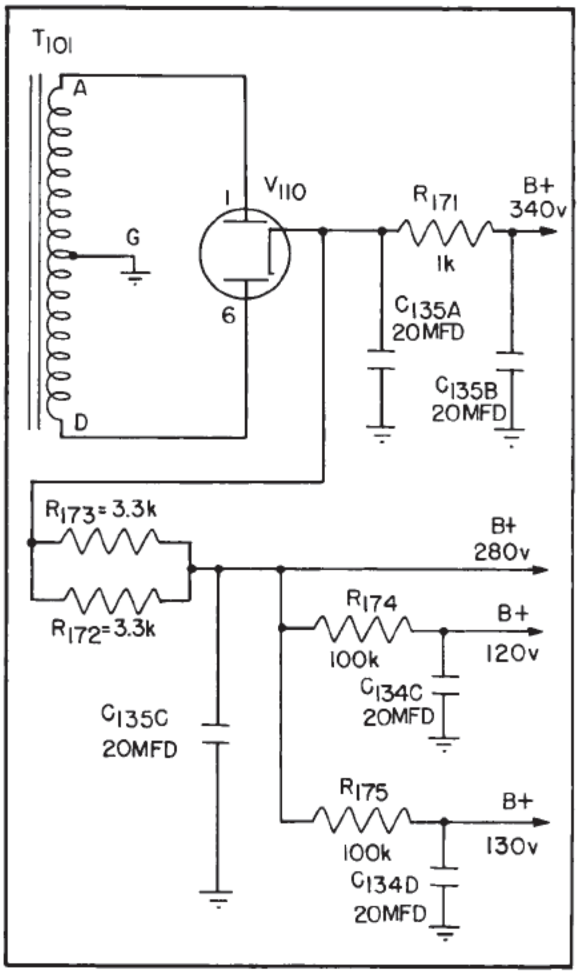

Figure 42-4 - OS8C/U power supply - intermediate voltage section.

42-5. The Low-Voltage B+ Supply

The low voltage section consists of the 220 volt center tapped section of T_{101}, full-wave rectifier CR_{101} - CR_{102}, and a Pi-section capacitive input filter. This section is illustrated in Figure 42-5.

CR_{101} and CR_{102} are selenium rectifiers connected as a conventional full-wave rectifier. They operate in a manner similar to that of V_{110}. Each rectifier conducts on an alternate half cycle. R_{167} and R_{168} act as surge current limiters to protect CR_{101} and CR_{102}. For instance, when the equipment is initially turned on, a high surge of current would flow through the selenium rectifiers due to the low opposition offered to the flow of current by C_{134A} while it is charging. R_{167} and R_{168} limit this surge of

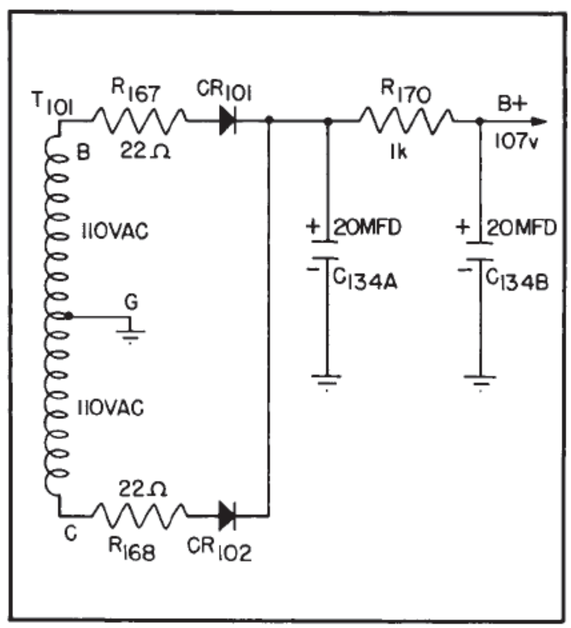

Figure 42-5 - OS8C/U power supply - low voltage section.

current to a safe value and prevent thermal breakdown of the rectifiers. The output of the full-wave rectifier is applied to a Pi-section filter which is composed of C_{134A}, C_{134B}, and R_{170}. The output of +107 vdc is taken across C_{134B} and provides plate voltage for the first vertical and horizontal amplifier stages.

42-6. The High Voltage B- Supply

The high voltage B- section consists of the 460v rms secondary winding of T_{101}, half-wave rectifier CR_{103}, and a Pi-section capacitive input filter. This section is illustrated in Figure 42-6.

CR_{103} is a selenium rectifier connected to T_{101} as a conventional half-wave circuit. The output of the half-wave rectifier is applied to a Pi-section filter which is composed of C_{133A}, C_{133B}, and R_{169}. The output of -560 vdc is taken across C_{133B} and provides cathode and grid potentials for the CRT. Note that the CR_{103} connections are reversed as compared to CR_{101} or CR_{102}, to provide an output which has a negative polarity with respect to ground.

A comparison of the Pi-section filter used in the high voltage section to the intermediate and low voltage filter sections is illuatrated in Figure 42-7.

The filter circuit used in both the intermediate and low voltage supplies is illustrated in Figure 42-7A. Note the large electrolytic capacitors used in this filter. These are necessary due to the relatively high load current drawn from the intermediate and low voltage supplies. The

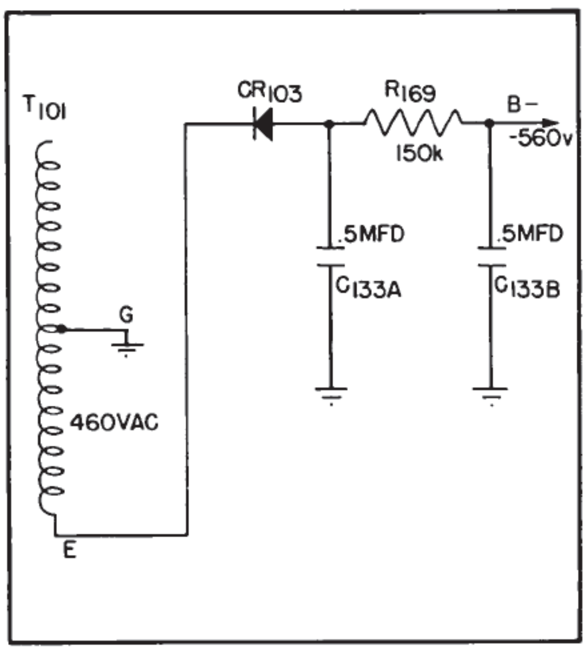

Figure 42-6 - OS8C/U power supply - high voltage section.

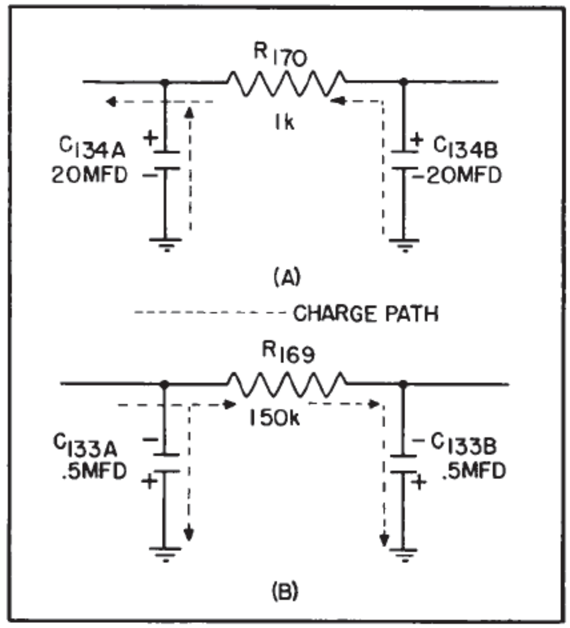

Figure 42-7 - OS8C/U (A) LV supply filter.
OS8C/U (B) HV supply filter.

large capacitors prevent the average output voltage from decreasing by providing a long discharge time constant. Since the filter capacitors present a low reactance (approximately 66 ohms at 120 cps) to the ripple frequency, a low value of resistance (1k ohm) may be used in the filter.

The high voltage supply filter is illustrated in Figure 42-7B. Compare the component values in Figure 42-7A and B. The load impedance of the HV supply is approximately 1.5 Meg ohms. A low load current is drawn from this supply. This high load impedance allows smaller filter capacitors to be used, while preserving the long discharge time constant. Since the capacity of the filter capacitors has decreased, the reactance, at the ripple frequency, will increase. This necessitates the use of a larger filter resistor. This reduction in filter capacitor size has some advantages. A physically smaller, unpolarized, paper capacitor may be used in place of the bulky, polarized, electrolytic capacitor. The reduced capacity of the input capacitor (C_{133A}) eliminates the need for a surge limiting resistor to protect CR_{103}.

Each of the power supply sections utilizes a capacitive input filter. Since the input capacitor can charge to approximately the peak value of the ac input, the PIV ratings of the rectifiers must be equal to at least twice the peak ac input. It is preferable, in practical circuits, that the PIV rating be GREATER than twice the peak ac input. Refer to Figure 42-6. In this

circuit, for example, C133A can charge to a peak value of -650v. This negative voltage is present on the anode of CR103. During the positive half cycle of the input to CR103, a positive voltage of 650v peak is applied to the cathode by the input. At the same time, -650v is applied to the anode by C133A. The total PIV is then 1300v. Therefore, CR103 should have a PIV rating greater than 1300v.

Note the absence of bleeder resistors in the three filter sections. The load in each section contains a resistive path to ground for dc. The loads connected to the filter sections act as bleeders to provide a discharge path for the filter capacitors.

The complete power supply schematic is illustrated in Figure 42-8. The three individual rectifier sections can be traced and compared to the simplified versions in Figures 42-4 through 42-7. Note the multisection electrolytic capacitors C134 and C135. Several capacitors are combined in one component unit to save space. C134, for instance, is composed of four separate 20MFD capacitors. Sections A and B are used as filter capacitors for the low voltage power supply. Sections C and D are used in the decoupling networks.

Q1. Assuming a PIV rating of 26v/cell, how many selenium rectifier cells must be used, and how must they be connected, to provide half wave rectification of 115 volts rms?

Q2. What is the primary purpose of the bleeder resistor in a power supply with a capacitive input filter?

REGULATED POWER SUPPLIES

The power supply used in the OS-8C/U oscilloscope is not regulated. Incorporating an unregulated power supply is common practice in the design of service type oscilloscopes, such as the OS-8C/U.

High quality (laboratory type) oscilloscopes used to measure voltage accurately, require some form of regulated power supply.

42-7. Voltage Regulation

In some equipment a voltage regulator circuit will be included between the power supply and the load. This is sometimes necessary due to changes in load current and variations in input voltage causing variations in B+. One method of regulation was discussed in Chapter 18. In that method of voltage regulation, glow tubes (called VR tubes) were used as the regulating elements. The glow tubes were connected in shunt with the load, and the total load impedance presented to the power supply was the impedance of the VR tube and load in parallel.

If, for instance, the load resistance increased, B+ would also tend to increase. A slight increase in B+ causes an increase in VR tube

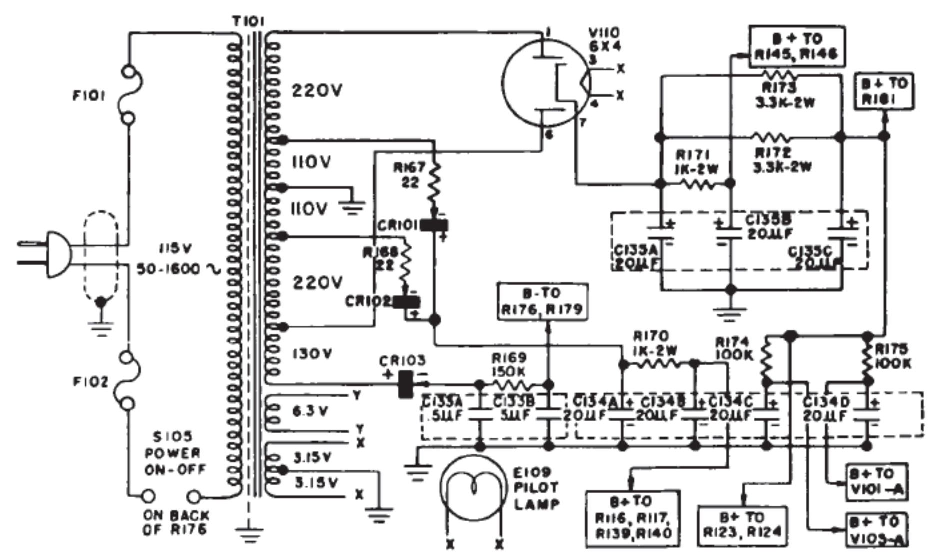

Figure 2-12. Power Supply

Figure 42-8 - OS8C/U power supply

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A1. Since the peak voltage is 162.6v, the PIV will be 325.2v, and a minimum of thirteen 26v cells must be connected in series.

A2. In a power supply with a capacitive input filter, the bleeder resistor has the primary purpose of providing a discharge path for the filter capacitors when the supply is turned off.

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ionization and a decrease in VR tube resistance. With an increase in load resistance and a decrease in the shunt VR tube resistance, the total load impedance remains fairly constant; and the variation in B+ is slight.

Glow tube regulators have several disadvantages: their current operating range is limited, they are relatively insensitive to slight variations in voltage, there is a difference in VR potential between minimum and maximum values of VR current; and the values of regulated voltage are relatively inflexible. Electron tube regulators may be used in areas that are not suitable for glow tube operation.

42-8. Electron Tube Voltage Regulator

The first electron tube regulator considered here is a simple series regulator circuit using a triode as the regulating element. The circuit is illustrated in Figure 42-9.

The input voltage to this circuit is taken from the filter section of the power supply. Triode V_1 acts as the regulating element, and is connected in series with the load. Potentiometer R_2 and the battery (Ecc) supply grid bias for V_1. Since Ecc is not disconnected when the input power is turned off, R_1 is included to limit grid current.

An electron tube acts as a variable resistor. With dc current flow from cathode to plate, the dc plate resistance (Rp) of the tube is equal to Eb/Ip. Since Ip can be controlled by E_c, changes in bias will cause changes in Rp. This variable

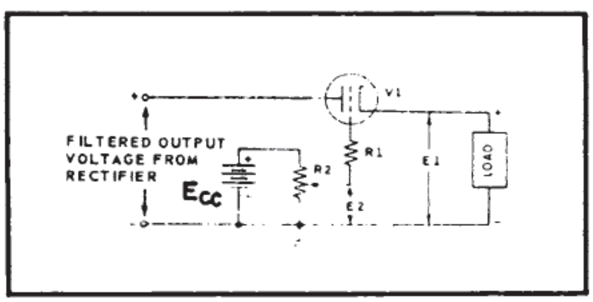

Figure 42-9 - Electron-tube voltage regulator employing fixed bias.

resistance characteristic can be used to control the voltage applied to the load.

Refer to Figure 42-10. In this example, assume that R_2 had been adjusted so that the load voltage equals 100v.

Cathode voltage (E_k) of V_1 is equal to the load voltage. Since the input is 200v and $E_b = E_{in} - E_k$, the plate voltage equals 100v. The grid to ground voltage is +90v. The bias is equal to the difference in potential between grid and cathode or 90v - 100v equals -10v bias. Note that V_1 is in series with the conduction path from the power supply to the load.

If an increase in power supply voltage occurs, the load voltage will tend to increase, causing an increase in the cathode potential of V_1. R_b of the tube increases due to the increase in bias, and the voltage drop across V_1 increases. The increase in voltage across V_1 is approximately equal to the increase in power supply output, and the load voltage remains essentially constant. Actually, there must be an increase in load voltage to cause an increase in the bias of V_1. This increase in load voltage is slight, however, compared to the increase in voltage across V_1.

This regulator will also compensate for changes in load current. If the load current was to increase, load voltage would tend to decrease. A slight reduction in load voltage would reduce the bias on V_1, and cause a large reduction in the Rp of V_1. The decrease in Rp would cause a reduced voltage drop across V_1, and load voltage would again remain essentially constant.

The fixed battery and variable resistor, R_2, may be eliminated by the use of a VR tube. This is illustrated in Figure 42-11. In this case, a VR tube holds the grid of V_1 at a fixed potential. The grid current limiting resistor may be eliminated since grid voltage is removed when the input voltage is disconnected. Circuit operation is the same as in Figure 42-10. This method of providing bias has a distinct disadvantage.

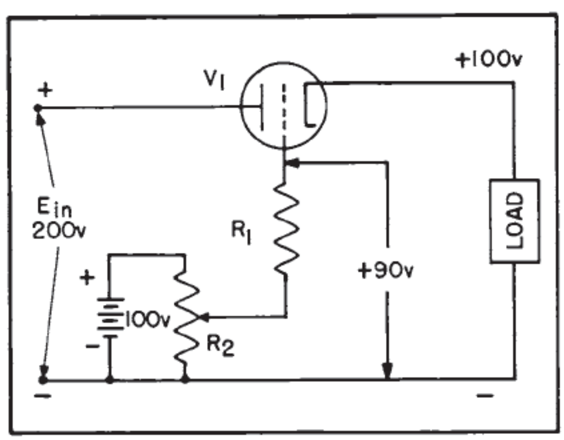

Figure 42-10 - Series triode regulator.

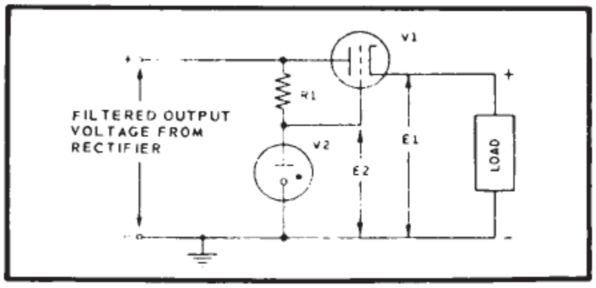

Figure 42-11 - Electron-tube voltage regulator employing a glow tube for the fixed bias.

There is no method of changing bias to compensate for changes in tube parameters.[1]

42-9. Shunt Detected Series Regulator

A regulator circuit with a high degree of stability and sensitivity is illustrated in Figure 42-12. The regulator circuit consists of two sections—the regulator circuit and the control circuit. Triode V_1 acts as the regulator and operates in the same manner as the circuit described in Section 42-8. The control circuit is composed of pentode V_2 and its associated circuitry.

The cathode of V_2 is held at a constant potential (positive) by VR tube V_3. The plate of the VR tube is connected to B+ through R_2. This allows the VR tube to ionize when the input voltage is applied. Resistors R_3, R_5, and potentiometer R_4 act as a voltage divider network in shunt with the load. A positive voltage is tapped from R_4 and applied to the control grid of V_2. The positive potential applied to the control grid of V_2 is lower than the positive potential on the cathode. R_4 controls the grid to cathode, or bias, voltage of V_2. R_1 is the plate load resistor of V_2. The voltage drop across R_1 is determined by the plate current of V_2. Since R_1 is connected between grid and cathode of V_1, the voltage drop across R_1 determines the bias on V_1. The Ip of V_2 controls the bias on V_1. For example, if the Ip of V_2 increases, the voltage across R_1 increases causing the bias applied to V_1 to increase.

R_4 is initially adjusted to establish a normal value of Rp for V_1, which produces the desired load voltage. If the load voltage was to increase, due either to an increase in input voltage or an increase in load resistance, the positive voltage at the wiper arm of R_4 would also increase, increasing the control grid voltage of V_2. Since the cathode of V_2 is being held at a constant potential by V_3, the positive increase in grid potential causes the bias on V_2 to decrease. This decrease in bias causes the Ip of V_2 to increase, increasing the voltage drop across R_1. The increased voltage drop across R_1 causes the bias on V_1 to increase, increasing the Rp of V_1. The voltage drop across V_1 increases counteracting the increase in load voltage. A decrease in load voltage would produce the opposite effects of those outlined above.

[1]A quantity or constant whose value varies with the circumstances of its application, as the radius line of a group of concentric circles, which the circle under consideration.

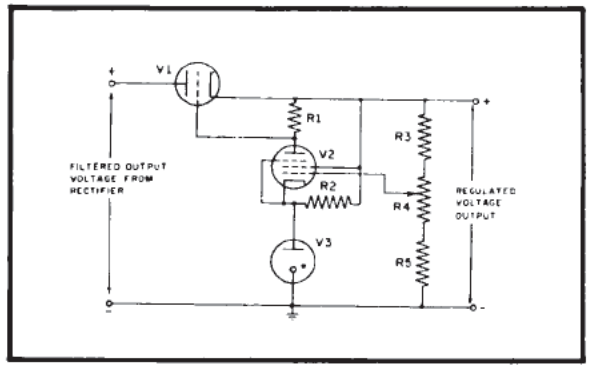

Figure 42-12 - Shunt detected series regulator.

A pentode is used in the control circuit due to its high amplification factor. Even slight variations in load voltage will be amplified sufficiently to operate V_1. Since total load current flows through triode V_1, this tube must be capable of passing a high current. Several triodes may be connected in parallel if the current capability of a single tube is not sufficient.

A general overview of a power supply which includes a regulator circuit is illustrated in Figure 42-13.

TRANSFORMERS:

Low voltage is stepped up by the transformer from 115 volts to 900 volts. Center tap provides a dividing point so that 450 volts are applied to each section of the 5U4G rectifier. The ends of the transformer alternately become positive and negative.

Center tap C on heater winding is used to force plate current to divide equally in each filament lead. If there is no center tap, a voltage divider of two equal 50 ohm resistors may be put across the secondary to produce the same effect.

Alternately positive and negative voltage is applied to the plates of the rectifier.

RECTIFIERS:

The two plates conduct alternately as each plate is made positive in turn by the secondary of the transformer. Pulses of current flow from the filament line to each plate in turn. The plates alternately become positive and negative with the

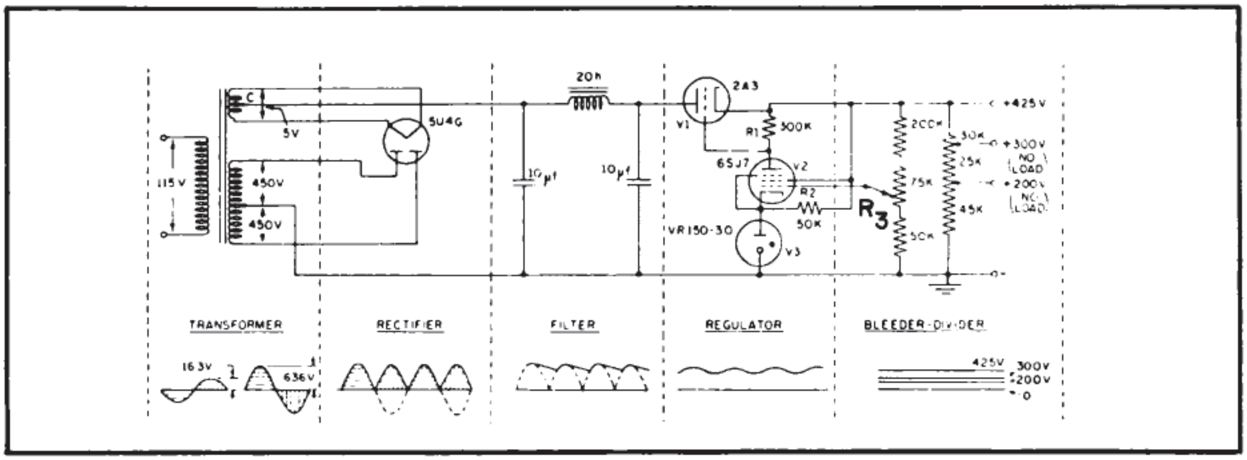

Figure 42-13 - Complete rectifier-filter-regulator-divider circuit.

applied ac, but the filament line will show a one-directional flow.

FILTER:

The capacitors charge when the rectifier conducts, and they discharge through the bleeder resistor and load when the tube is not conducting.

The choke builds up a magnetic field when the tube draws current. The field collapses as current decreases, tending to keep a constant current flowing in the same direction through the bleeder resistor and the load.

The capacitive input (illustrated) gives higher voltage output and is used with low current drain loads.

The choke input gives steadier output with less ripple under heavy load conditions.

REGULATOR:

If the load draws more current or if the ac input voltage decreases, the terminal voltage of the power supply decreases.

Resistor R_1, tube V_2, and gas-tube V_3 are in series across the rectifier terminals. V_3 holds the cathode of V_2 at a constant positive potential with respect to ground, and setting of R_3 determines bias on V_2. A fall in terminal voltage causes more negative bias on V_2, less current through V_2, hence, less current through R_1. Less IR drop across R_1 causes less negative bias on V_1. V_1, then acts as a lower value resistor, and terminal voltage decrease is checked.

BLEEDER-DIVIDER:

As a bleeder, the resistor is for safety to discharge the capacitors when power is removed.

As a load resistor, it acts as a stabilizer to protect the voltage regulator if the load is removed, and to improve the regulation.

A voltage divider meets the requirements of a load resistor and a bleeder, but in addition has taps placed at intervals for voltage at less than the maximum.

It is usually grounded at the lower end but may be grounded at any higher point to provide a negative output.

Q3. Why does an increase in load current produce a decrease in output voltage in an unregulated power supply?

Q4. A power supply is connected to a load with a VR105 glow tube used as a regulator. Why must the power supply output voltage be greater than 105v?

Q5. What effect would a regulator circuit have on power supply ripple?

EXERCISE 42

1. What determines the peak inverse voltage rating of a selenium rectifier cell?
2. List the advantages and disadvantages of selenium rectifiers.
3. Explain the methods of obtaining several output voltages from one secondary winding.
4. Why does the intermediate B+ supply use a full-wave vacuum diode rectifier circuit instead of a selenium rectifier circuit?
5. List the output voltages of the OS-8C/U oscilloscope power supply.
6. Explain the meaning of B-.
7. Why does the high voltage supply use smaller filter capacitors?
8. What is the purpose of resistors R_{167} and R_{168} in the OS-8C/U oscilloscope?
9. Why are resistors R172 and R_{173} connected in parallel in the OS-8C/U oscilloscope power supply?
10. Does the OS-8C/U oscilloscope power supply use voltage regulators? Why?
11. Explain the operation of the shunt detected series regulator when the load voltage tries to decrease?

A3. An increase in load current causes the voltage drop across the internal impedance of the power supply to increase, reducing the output voltage.

A4. The power supply output must be greater than 105v because the ionization potential of a VR tube is greater than the regulated voltage it will maintain.

A5. Since the ripple voltage appears to the regulator circuit as a continual increase and decrease in power supply output, the regulator circuit would decrease the ripple amplitude. The magnitude of ripple reduction would depend on the sensitivity of the regulator circuit.

CHAPTER 43

SWEEP CIRCUITS

Previous chapters have dealt with the generation of an alternating current from a direct current source by the use of an oscillator. The oscillators (generators) discussed previously produced only sinusoidal waveforms. However, the proper operation of many electronic devices depends on circuits which produce voltages and currents having nonsinusoidal waveforms. The most common of these nonsinusoidal waveforms (used in television and radar equipment, etc.) are the SAWTOOTH waveform and the SQUARE or RECTANGULAR waveforms.

Just as the sine wave varied in a definite manner over a specific time and repeated this cycle at a definite frequency, so do the sawtooth and square waves. When the sawtooth or square wave is repetitive in nature, the circuit producing it is called a NONSINUSOIDAL OSCILLATOR.

There are many different types of nonsinusoidal oscillators, each having a specific name and function. The purpose of this chapter is to discuss these various oscillators, starting with the basic types and progressing to the complex types. Although these oscillators will be discussed in relation to their operation in the sweep circuits of an oscilloscope, the basic operation remains the same when applied to other types of equipment.

The first part of this chapter will discuss the purpose of the sweep circuits in an oscilloscope and, utilizing block diagrams, will show the relation of the sweep circuits to the other oscilloscope circuits. Then the various types of sawtooth generators, beginning with the gas tube type and advancing to the electron tube type will be discussed. A portion of the chapter is devoted to the description and analysis of various types of MULTIVIBRATORS. Finally the operational analysis of the sweep circuit oscillator in a Navy oscilloscope will be given.

43-1. Waveform Observation

One of the most general uses of the cathode-ray oscilloscope is the observation of the shape of voltage and current waveforms in electrical circuits. For this purpose a graph of the waveform is made, with the voltage or current plotted vertically and time plotted horizontally. A simple example of such a graph is shown by the voltage and current sine waves in Figure 43-1.

Notice that the time axis is marked in degrees and progresses from the left towards the right.

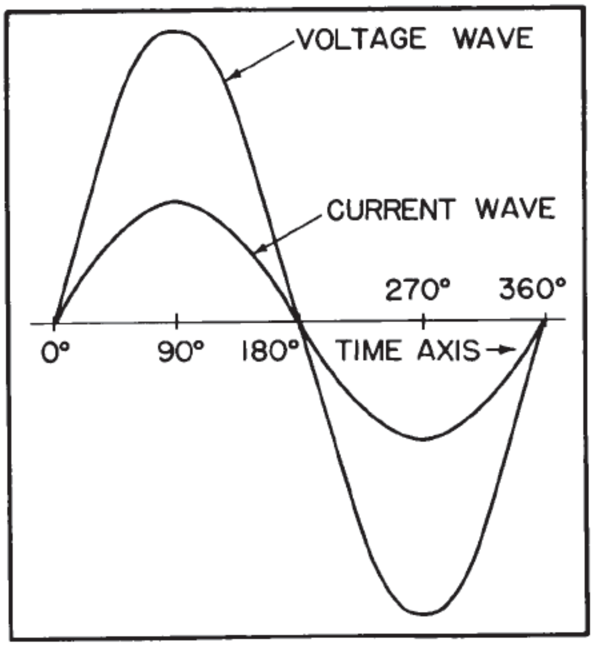

Figure 43-1 - Voltage and current waves in phase.

The instantaneous amplitude of the waves at any instant is plotted vertically on the graph. Since this is the conventional way in which voltages and currents are visualized and used for calculation, the oscilloscope must present its information in this form if it is to be of value. Normally only one waveform is presented at a time, both current and voltage were shown in Figure 43-1 merely for reference.

In order to present a display, such as the voltage wave of Figure 43-1, on the screen of an oscilloscope, a voltage must first be impressed on the horizontal deflection plates of the cathode-ray tube (CRT). This voltage is called a HORIZONTAL DEFLECTION VOLTAGE and must move the electron beam from left to right across the screen (as seen from the front) at a constant rate of speed to form a time scale exactly like the line 0° to 360° in Figure 43-1.

The electron beam strikes the screen at only one point at any instant. To form an image, a rapid succession of spots of light must be

produced side by side on the screen. Since the light on the screen does not die out immediately, and, the human eye retains an image for approximately one sixteenth of a second, the succession of dots of light appear as a continuous line. If the horizontal deflection voltage causes the spot of light to retrace its path more than 16 times per second, the image will be maintained on the screen. The horizontal deflection voltage is also called a SWEEP VOLTAGE because it sweeps the spot across the screen. If only the sweep voltage is applied to the CRT the spot will sweep back and forth along the line 0^o to 360^o (Figure 43-1). The line or trace thus formed by the moving spot is called the TIME BASE, since its length represents a definite period of time. In producing the time base the spot must move uniformly across the screen from left to right (0^o to 360^o) and upon reaching the right hand limit (360^o) move as rapidly as possible back to the left hand limit (0^o). The sweep voltage that will produce this uniform motion of the spot across the screen and the rapid return is called a sawtooth voltage, because the shape of the voltage waveform resembles the cutting edge of a saw, A sawtooth voltage waveform is shown in Figure 43-2.

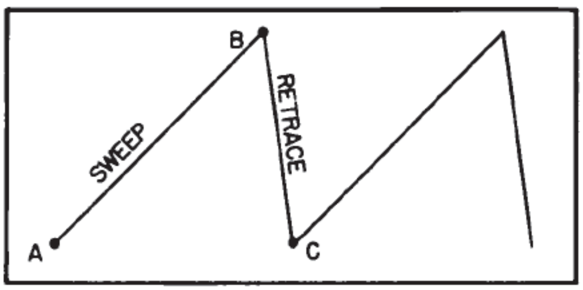

Figure 43-2 - Sawtooth waveform.

In Figure 43-2 time is plotted horizontally and amplitude is plotted vertically.

If one complete sine wave is to appear on the screen when a sine wave is applied to the vertical deflection plates, the sawtooth sweep voltage applied to the horizontal plates must have the same frequency as the sine wave. This causes the beam to sweep across the screen once each time the sine wave completes one cycle.

The voltage rise of the sawtooth waveform must be linear. The time base in Figure 43-2 will be linear with time providing that for any given segment of line AB, the amount of rise in a specified time is the same as for any other equal segment. In other words, an amount of voltage change for a given change in time will be the same any place along line AB. The time between A and B (Figure 43-2) represents the sweep portion of the sawtooth waveform. In order to return the beam rapidly to the left side of the screen in preparation for the next sweep the voltage must fall from point B to point C as quickly as possible. This is known as the RETRACE or FLYBACK portion of the waveform. The slope of line BC is greatly exaggerated in Figure 43-2, however, it is seen that the time between points B and C is still a small fraction of the time between points A and B. The time between B and C is called the FLY-BACK TIME, since it represents the time during which the spot is being moved back to the starting point. Because the fly-back or retrace time is so very short, the electron beam is swept over the screen too fast to cause emission of much light. Accordingly, the retrace line is usually very dim in relation to the swept image, however, even this dim light is occasionally a problem and some oscilloscopes employ special circuits to lower the intensity of the beam during retrace. This is done by cutting off (BLANKING) the CRT during flyback (retrace) time with a negative pulse applied to the control grid. A positive pulse may be applied to the cathode to obtain the same result. The BLANKING PULSE, as it is called, is generated in the sweep circuit along with the sawtooth voltage and occurs only at the time of flyback.

Simultaneous application of the sine wave to the vertical plates and the sawtooth wave to the horizontal plates will cause the sine wave to be reproduced on the screen of the oscilloscope. The manner in which this is accomplished is shown in Figure 43-3. Since a detailed account

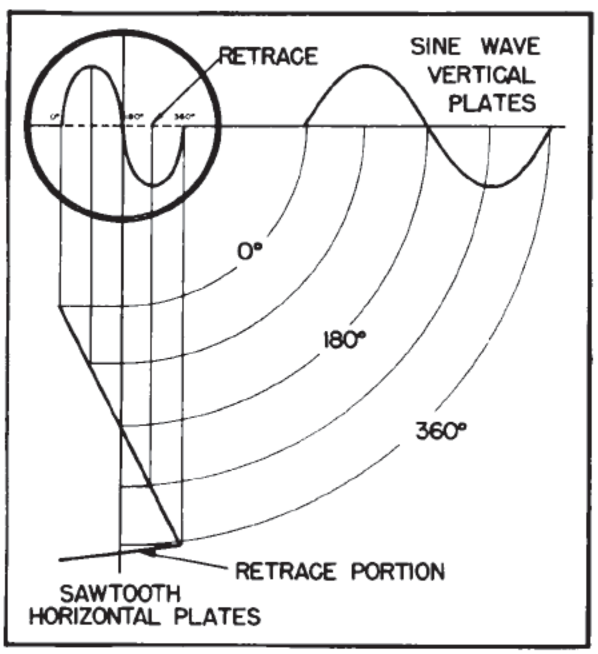

Figure 43-3 - Reproduction of pattern on scope screen.

of this action was given in section 14-22 it will not be repeated at this time.

It is evident in Figure 43-3 that the beginning of the sawtooth wave and the beginning of the sine wave both occur at 0^{o}. It is necessary that the beam start at the same point for every trace in order to avoid a blurred or moving image. The part of the sweep circuit that forces the sawtooth to begin at the same time as the sine wave is called the SYNCHRONIZATION or SYNC circuits.

In an ideal condition the retrace time is instantaneous. It is the responsibility of the sweep circuits to produce a sawtooth voltage with the shortest retrace time possible. Figure 43-4 illustrates the effects of a varying retrace times upon the scope presentation of the sine wave. Notice that the retrace time subtracts from the time of the trace.

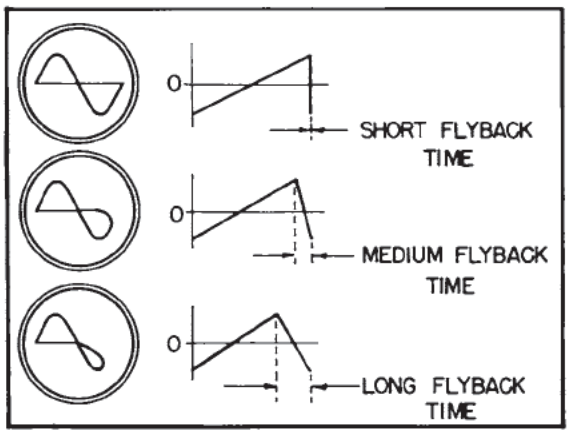

Figure 43-4 - Effects of retrace time on the scope presentation.

Another important function of the sweep circuits is to insure that the sawtooth voltage waveform has a very linear rise in voltage with respect to time. If the sawtooth voltage waveform rises linearly, the beam will move across the CRT screen at a linear rate, thus producing a uniform time base upon which any waveform can be plotted accurately with respect to time. Figure 43-5 shows the results of using a sawtooth voltage with a nonlinear rise time. Note that the waveform on the CRT is very distorted because the nonlinear rise of the sawtooth voltage produced a nonlinear time base.

It has been pointed out that the purpose of the sweep circuits is to produce a sawtooth voltage of the proper duration (frequency) with a linear rise time and a fast retrace time.

Figure 43-6 shows a very basic block diagram of an oscilloscope.

The sawtooth waveform from the sweep generator is amplified by the horizontal deflection amplifier before being applied to the horizontal

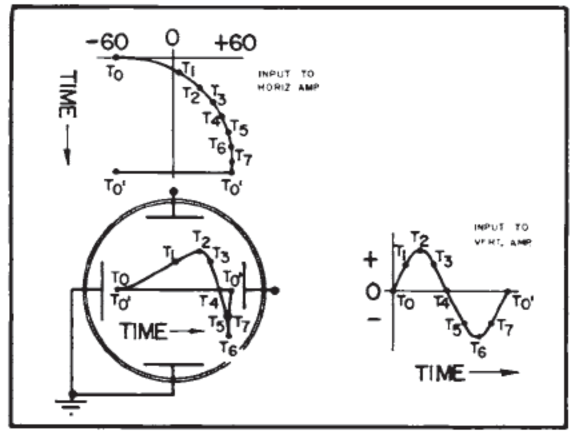

Figure 43-5 - Effects of using a nonlinear sweep voltage.

(H) deflection plates. Note that there is a terminal connected to the sweep generator to which a signal from some external source may be applied in order to insure that the start of the sawtooth voltage waveform is synchronized with the start of the vertical input signal.

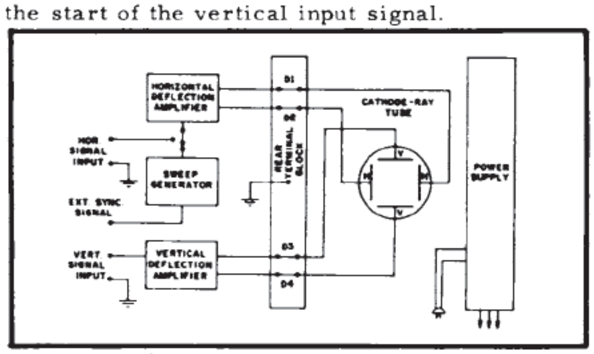

Figure 43-6 - Block diagram of a cathode-ray oscilloscope.

Figure 43-7 shows a detailed block diagram for the OS-8C/U oscilloscope. The sweep circuits consist of: the sweep circuit oscillator, the sync selector, the sync amplifier and the intensity modulation amplifier. These four blocks are the equivalent of the sweep generator block in Figure 43-6, the basic oscilloscope block diagram. Analysis of the blocks will commence with the sweep oscillator, which can be one of many different types. Several circuits will be analyzed in this chapter which can serve as sweep oscillators.

Q1. What functions must the sweep circuits perform?

Q2. To which deflection plates would the output of the sweep circuits be applied and when?

Q3. What is blanking?

A1. The sweep circuits supply a linear sawtooth voltage waveform with a fast retrace or flyback time. This waveform must be of the proper duration and it must be synchronized to start when the vertical input signal starts.

A2. The output would be supplied to the horizontal deflection plates when a linear time base is desired.

A3. The cutting off of the electron beam during retrace time.

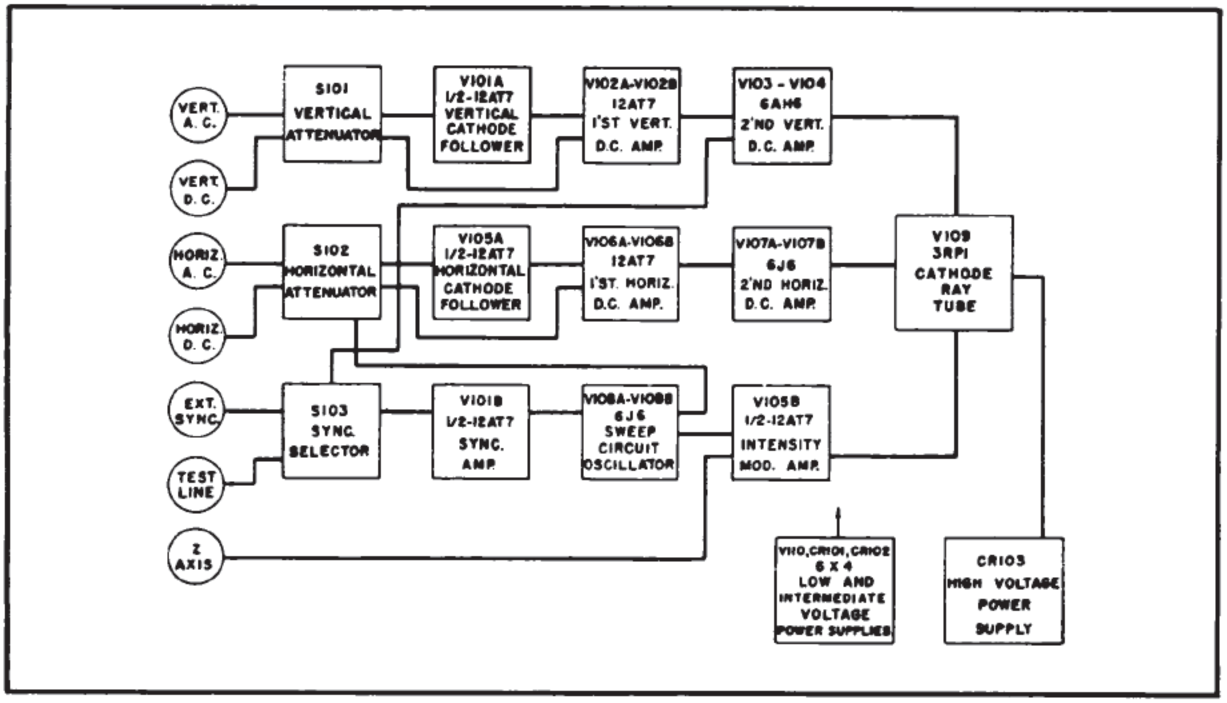

Figure 43-7 - Detailed oscilloscope block diagram.

SAWTOOTH GENERATORS

It was previously stated that the purpose of the sweep circuits is to provide a sawtooth voltage waveform with a very linear rise time and a very fast retrace.

The simplest method of obtaining this type of waveshape is by means of a gas-tube RELAXATION OSCILLATOR. This oscillator is one in which the output shows abrupt changes in voltage usually brought about by charging or discharging a capacitor through a resistance. Another sawtooth generator to be analyzed will be the HARDTUBE SAWTOOTH GENERATOR. It will be found that most sawtooth generators use a capacitor charging slowly through a large resistance and then discharging quickly through a small resistance to produce a sawtooth voltage.

43-2. Neon Tube Sawtooth Generator

Figure 43-8 illustrates the use of resistance and capacitance to produce a sawtooth waveform. When the switch is in position (1), the series combination of the capacitor and resistor are connected across a 200 volt source. It is assumed that the values of resistance and capacitance are such that a relatively long time constant will result. The instant the switch is closed, the capacitor will begin to charge at an expotential rate. This will produce the rise time of the sawtooth waveform being developed. In order to have a linear rise of the sweep portion of the sawtooth wave, only a small portion of the exponential curve may be used. Notice that Figure 43-8 uses only the very beginning of the charge curve of the capacitor. This can be shown in the following manner.

Assume that full charge, or 100% on the universal curve in Figure 43-9, is equal to 200 volts. If the switch is left in position (1) long enough for the capacitor to charge to 20 volts, this would be approximately 10 percent of full charge or approximately one tenth of one time constant. Thus, time zero (T_O) to time one (T_1) in Figure 43-8 represents only one tenth of one time constant. It can be seen that only a

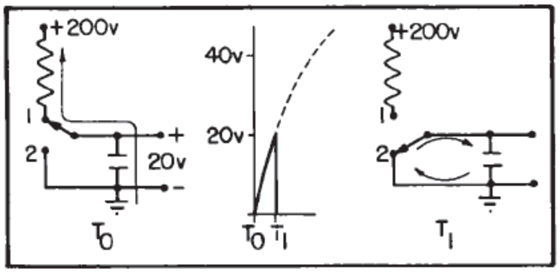

Figure 43-8 - Generation of a sawtooth voltage waveform.

very small, and therefore relatively linear, portion of the exponential charge curve is used.

At time T_1, when the capacitor has reached 20 volts, the switch is thrown to position (2). Since there is no resistance in the discharge path, the potential of the capacitor will fall very rapidly from 20 volts to zero volts. This is shown by the nearly straight line representing the retrace portion of the sawtooth wave in Figure 43-8.

If the manual switch were replaced by an electronic device which would perform the same function, a continuous sawtooth wave could be generated. The neon glow tube (as described in section 18-5) is just such a device.

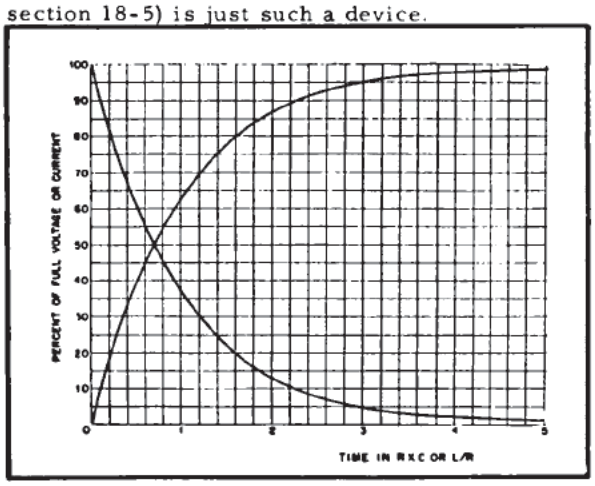

Figure 43-9 - Universal time constant curves.

Until the potential across this type of tube reaches a value high enough to ionize the gas, the tube presents an almost infinite impedance. However, once ionized, a very small voltage is sufficient to keep the current flowing and until the voltage across the tube falls below the value required to maintain the ionization the tube has a low impedance. When the voltage falls below this value, the gas deionizes and current flow ceases. The potential at which the gas ionizes and conduction begins is called the firing potential of the tube and that at which deionization takes place is known as deionization potential. The tube can be considered as a switch which is open when the tube is not ionized and closed when it is ionized.

When the switch in Figure 43-8 is replaced with a neon glow tube the circuit becomes a simple neon tube sawtooth generator. The manner in which a neon tube sawtooth generator creates a sawtooth wave is illustrated in Figure 43-10.

When a constant source voltage is applied to this circuit, the voltage across the capacitor rises from zero, approaching the full supply voltage along a normal RC charging curve (Figure 43-10). The charge path of the capacitor is through the relatively large value of resistor R. The voltage across the neon tube is the same as the voltage across the capacitor because these components are in parallel. The neon tube acts as an open switch until the voltage across it reaches the firing point. At the firing potential, the neon tube ionizes and forms a discharge path for the capacitor. The capacitor discharges very rapidly until the voltage falls to the deionizing potential of the neon tube, at which time tube conduction stops and the tube becomes an open switch again. The capacitor then begins to charge again toward the supply voltage. The voltage rises along the RC curve to the firing potential of the neon tube, and then falls again. This process continues as long as a dc supply is maintained.

The frequency of a sawtooth is the number of times the voltage rises and falls per second. This frequency can be varied by changing the firing and deionizing potentials, but this means of variation requires a change in neon-tube characteristics. A simpler method of frequency control is to vary the value of the resis-

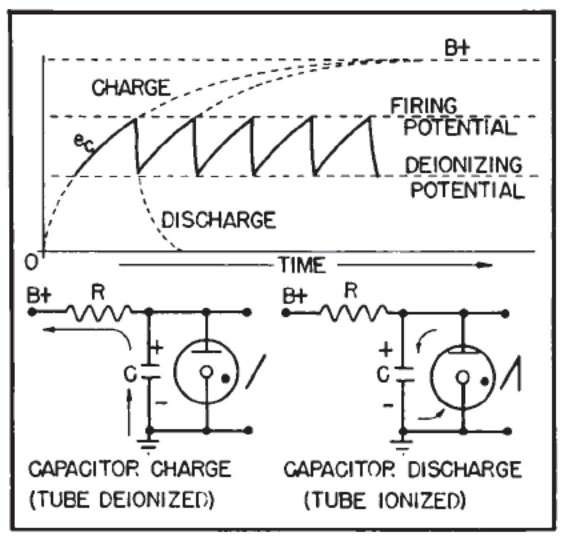

Figure 43-10 - Variation of capacitor voltage in neon sawtooth generator.

tor, the value of the capacitor, or the magnitude of the supply voltage. Since the resistor and capacitor form a time-constant circuit, an increase in the value of either element increases the time for a given amount of charge to be developed across the capacitor from a fixed source. Therefore, a lower frequency may be expected with increased capacitance or resistance values because f = 1/t and if the time of each wave increases the frequency must decrease. This condition is shown in Figure 43-11.

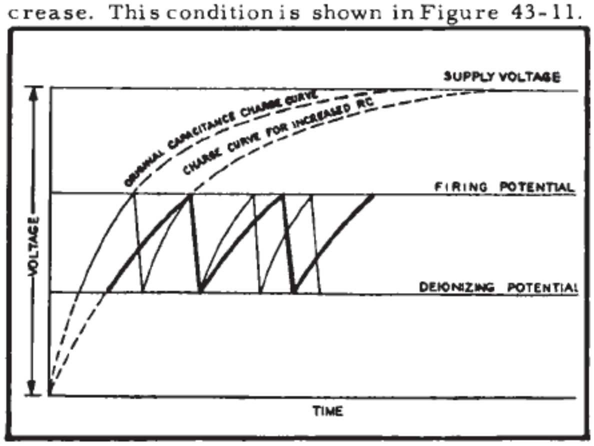

Figure 43-11 - Increase in RC causing decrease in frequency.

Very often the sawtooth generator will have two frequency controls as shown in Figure 43-12. The switch which changes the capacitor used is called the COARSE FREQUENCY CONTROL. The variable resistor is the FINE FREQUENCY CONTROL. By using a variation in the value of R and C to change the frequency, the linearity of the output sawtooth voltage waveform is not affected. This is true because the linearity is determined by the percent or the amount of the

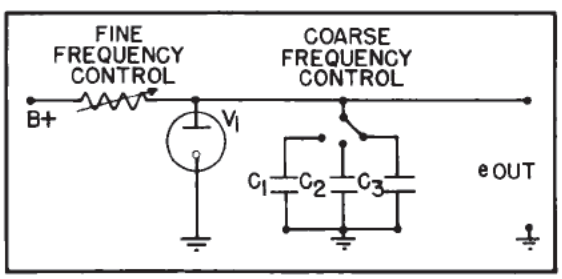

Figure 43-12 - Methods of controlling frequency.

charge curve used. The percent of the charge curve used when the capacitor charges can be changed only by changing B+, changing the ionization potential, or changing the deionization potential of the gas diode. In other words, if the capacitor in a neon tube sawtooth generator charges to 63% of the B+ value before the tube ionizes, it will always use a portion of the first 63% of the charge curve regardless of changes in the value of R and C. Thus, the linearity of the rise time will not change when R and C are varied, even though the duration of the rise time and the frequency will change.

The frequency of the neon tube sawtooth generator may also be changed by varying the supply voltage (B+), though this is not normally done. If the supply voltage is increased, the capacitor can charge to the firing potential of the tube faster because the firing potential is a smaller portion or percent of the new supply voltage. Thus, the frequency output increases when the supply voltage is increased as shown in Figure 43-13. Because the firing potential is a smaller percent of the supply voltage, a lower portion of the charge curve is used and thus linearity has been increased as a result of increasing the supply voltage.

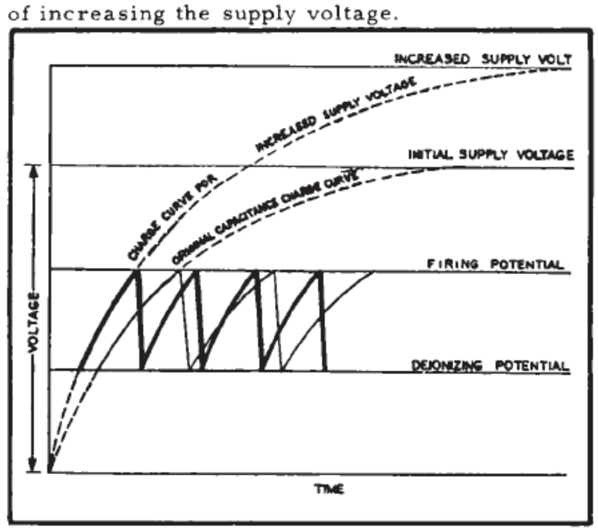

Figure 43-13 - Frequency changes resulting from changes in circuit constants of neon sawtooth generator.

It is evident from Figure 43-13 that in order to produce a linear rise in the sawtooth waveform, the firing potential of the neon tube must be very low with reference to the B+ value. Thus the lowest part of the charge curve can be used. It is important that the internal resistance of the neon tube, when ionized, be very low so that the capacitor can discharge quickly, keeping retrace time very short.

The amplitude of the sawtooth waveform produced by this circuit is equal to the difference between the ionizing and deionizing potentials of the neon tubes. These potentials are fixed, by the manufacturer, for a particular tube and are changed only by replacement with a different tube number.

Q4. What is the condition of the neon tube during rise time? During retrace time?

Q5. If the capacitance decreased what would happen to: the sawtooth wave duration, the sawtooth wave amplitude, the sawtooth wave frequency, and the linearity of the sawtooth wave?

Q6. If B+ decreased, what would happen to the sawtooth wave duration, amplitude, frequency, and linearity?

43-3. The Thyratron Sawtooth Generator

The neon tube used in section 43-2 is, in reality, a cold cathode gas diode. A more versatile sawtooth generator can be constructed using a gas-filled triode or tetrode as the discharge switch. A gas-filled triode or tetrode is called a THYRATRON. The schematic symbol for a thyratron tube is the same as the symbol for a vacuum tube with the exception that a black dot is placed in the lower right-hand area of the symbol. The presence of this dot on any tube symbol indicates that the tube is a gas-filled tube. The symbol for a triode type thyratron is shown in Figure 43-14.

To visualize the operation of a thyratron, assume that the cathode is heated, a space charge exists around the cathode, the plate voltage is zero, and that the control grid has been purposely connected to the cathode through an external wire. If a small positive voltage is applied to the plate, the electrons near the outer edge of the space charge will be attracted to the plate. Since the area between cathode and plate is filled with atoms of gas, a number of collisions occur between the gas atoms and each electron in transit to the plate. Because the plate voltage is low and the resulting electrostatic field is weak, these electrons have very little kinetic energy.

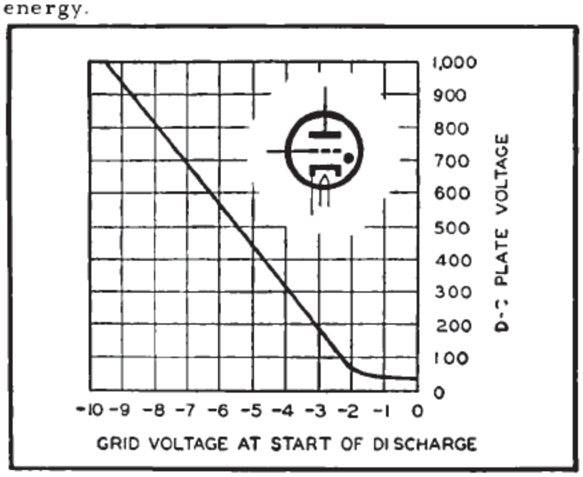

Figure 43-14 - Thyratron symbol and grid characteristics.

By increasing the plate voltage the electrostatic field between plate and cathode is strengthened, imparting a higher velocity to the attracted electrons. If the plate voltage is increased sufficiently, the electrons will gain enough energy to collide violently with the gas atoms, causing them to become ionized. The positive ions thus created drift rapidly to the area of the cathode and neutralize the effects of the space charge. Once the space charge is neutralized the tube becomes a virtual short-circuit.

Up to this point the operation of the thyratron has been essentially the same as that of a gas-filled diode or neon tube. However, the effects of the control grid have not been taken into consideration. If instead of being connected to the cathode the control grid is made negative, an additional force will be exerted on the space charge electrons. The negative grid will repel the electrons making it necessary to raise the plate voltage to a higher potential before the electron velocities become high enough to cause ionization. Thus, by making the control grid negative the ionization potential can be raised to a higher value.

Once the tube becomes ionized the positive ions thus formed will be attracted to any area of the tube in which a negative charge exists. If the grid is made negative in an effort to stop the conduction of the tube, the positive ions collect around the control grid and neutralize its negative charge. An increase in negative grid potential simply causes the sheath of positive ions surrounding the control grid to become more dense, again cancelling the effects of the negative grid. Thus it can be seen that ONCE THE TUBE IONIZES THE CONTROL GRID POTENTIAL HAS NO EFFECT ON PLATE CURRENT. To stop the flow of plate current the plate circuit must be opened, or the plate voltage must be reduced below the deionization potential.

A graph showing the amount of plate voltage required to fire a FG-57 type thyratron at various values of negative grid voltage is illustrated in Figure 43-14. For example, the -7 volt line intersects the curve at about 700 volts showing that if the grid is biased at -7 volts, the plate voltage must be raised to about 700 volts to make the tube fire. If the bias is reduced to about -4 volts, only 300 volts of plate voltage are required to fire the tube. The ability of the control grid voltage to control the firing potential of the tube makes the thyratron extremely useful for trigger circuits, motor control circuits, and sweep generators.

In the typical circuit for the thyratron sawtooth generator, shown in Figure 43-15, the charging and discharging of the capacitor takes place in exactly the same manner as in the neon tube sawtooth generator.

A4. The neon tube is deionized during rise time and ionized during flyback time.

A5. Duration decreases, amplitude remains constant, frequency increases, linearity remains unchanged.

A6. Duration increases, amplitude remains constant, frequency decreases, linearity decreases.

When plate voltage is applied to the circuit the capacitor charges over the path marked by the light arrows. Since the charging current flows through the series variable resistor, a certain amount of time is required for the capacitor to charge. As the voltage across the capacitor rises the thyratron plate voltage rises and approaches the firing potential of the tube. When the firing potential of the tube is reached

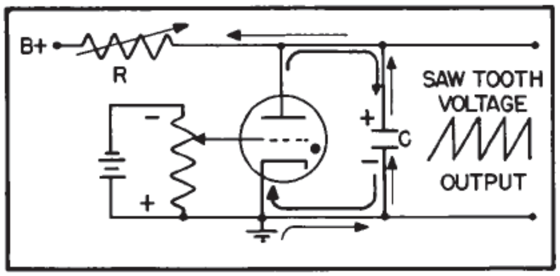

Figure 43-15 - Simple thyratron sawtooth generator.

the tube ionizes placing a short across the capacitor. The capacitor discharges through the tube (path shown by heavy arrows) until the voltage remaining across the capacitor reaches the deionization potential. At this point the tube deionizes removing the short-circuit from across the capacitor. This permits the capacitor to begin charging again, initiating a new cycle of operation.

The amplitude of the voltage rise on the capacitor is controlled by a negative bias on the grid of the thyratron tube. This bias is supplied by a fixed negative voltage source. Any voltage on this voltage divider must be negative since the positive end of the battery is connected to ground potential. The amplitude of the output sawtooth waveform is determined by the negative potential on the grid of the thyratron. This method of amplitude control has a limitation in that a change of frequency accompanies a change of amplitude as shown in Figure 43-16.

Note that when bias is increased, firing potential increases and amplitude increases but frequency decreases because the capacitor takes longer to reach the higher firing potential.

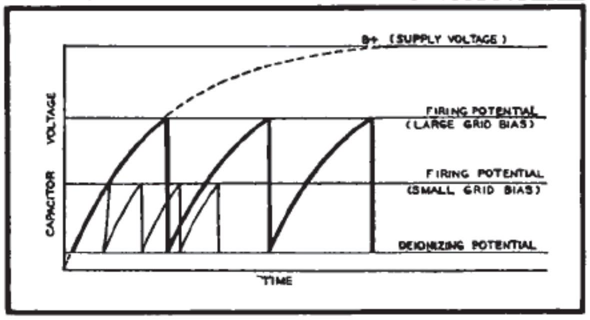

Figure 43-16 - Change of amplitude and frequency of thyratron sawtooth generator by change of grid bias.

The output has a less linear rise time when the amplitude is increased because a larger portion of the charge curve is used.

In addition to the effect of grid bias on frequency the frequency of a thyratron sawtooth generator may be varied in the same manner as in the neon sawtooth generator. In other words, an increase in the value of the resistor or capacitor, or a decrease in the supply voltage will cause a decrease in frequency, etc.

It can be seen from Figure 43-16 that the rise in voltage of the sawtooth wave is not linear but follows the exponential charging curve of the capacitor. The lower portion of the curve is very nearly linear, however, and by using a dc supply voltage that is much higher than the firing potential of the tube, a rise that is sufficiently linear for most purposes can be obtained at the output.

The oscillations of a gas-tube relaxation oscillator are not stable in frequency. Any slight changes in R, C, or the firing potential due to varying temperature, etc., will cause the frequency to change.

The thyratron oscillator, however, can be synchronized with a constant frequency. This is accomplished by capacitively coupling a signal, of the desired frequency and proper amplitude, to the grid of the thyratron. The circuit would be the same as the circuit in Figure 43-15 except that one lead of a coupling capacitor would be connected to the movable arm of the bias potentiometer (grid) and the other lead would be connected to a source of synchronizing voltage.

The waveforms of a synchronized thyratron oscillator are shown in Figure 43-17, which is also used to illustrate the manner in which the sync signal controls the frequency of the oscillator. The natural frequency of the thyratron oscillator (shown dotted) is adjusted to some value slightly lower than the desired output frequency. The desired output of this oscillator is 500 cps and the natural frequency is set at 490 cps. Then, an ac sync signal is

applied to the grid. The frequency of the sync signal is the exact desired output frequency (500 cps). It can be seen by the dotted sawtooth wave that without the synchronization signal the oscillator would fire at point A. However, when the synchronizing voltage is present on the grid the firing potential alternately increases and decreases in accordance with the grid signal. Notice that the sync signal and the firing potential variation are 180° out of phase with each other. A decrease in bias (positive direction) will cause the firing potential to decrease. Therefore, the tube actually fires on the positive alternation of the sync signal. At some time during the synchronizing cycle the lowering of the firing potential will coincide with the rising capacitor voltage, causing the thyratron to fire slightly ahead of time at point B. On the next cycle the voltage across the capacitor reaches the firing point at D, where it normally would have fired at C. The time of each oscillation is thus reduced from A and C to B and D, and the oscillator is now locked to the frequency of the injected voltage.

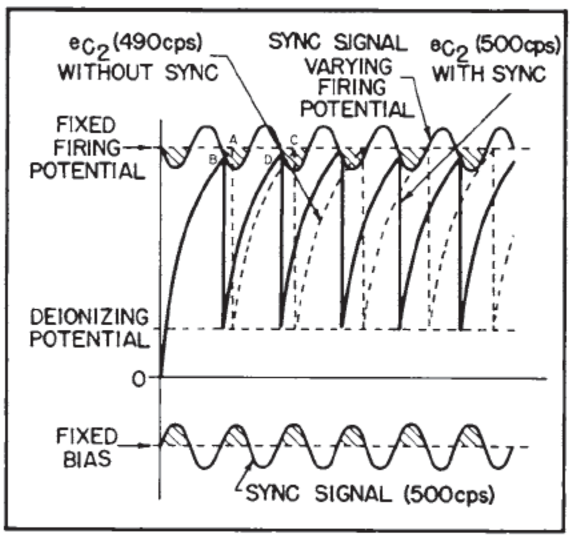

Figure 43-17 - Synchronization of thyratron-sawtooth generator with sine wave.

In addition to being locked at the frequency of the synchronizing signal, the thyratron oscillator can also be operated at a submultiple of the synchronizing voltage. Assume for example, that two cycles of a given signal are to be viewed on the screen. In order for two cycles to appear on the trace, each cycle of the sawtooth sweep voltage must last twice as long as each cycle of the signal to be viewed. In terms of frequency, the sweep frequency must be one-half the frequency of the signal voltage.

Since the signal frequency is twice as high as the sweep frequency, each cycle of the signal cannot be used to trigger each cycle of the sweep oscillator. The sweep oscillator can, however, be triggered by every second cycle of the signal voltage as shown in Figure 43-18.

In this illustration the signal to be viewed has a frequency of 1,000 cycles per second. When used as sync, this signal causes the firing potential to rise and fall at the rate of 1,000 times per second.

By adjusting the time constant of the sawtooth forming capacitor so that the natural frequency of the sweep voltage (dotted waveform) is slightly lower than 500 cycles per second, every other positive alternation of the signal will lower the firing potential of the tube slightly ahead of the point at which the tube would have fired without sync. This forces the oscillator to lock in at a

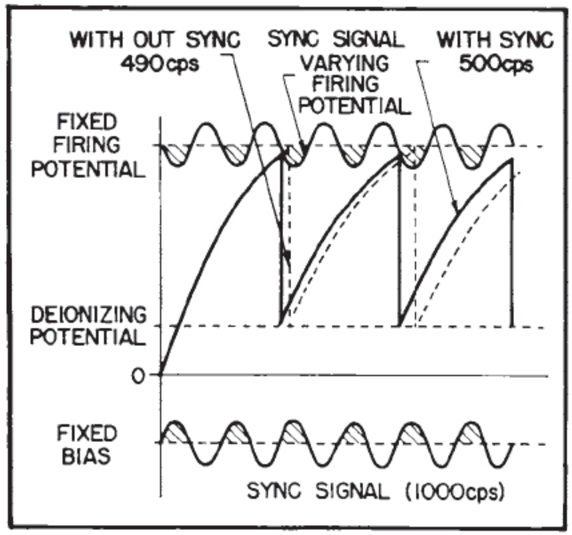

Figure 43-18 - Synchronization with a multiple frequency.

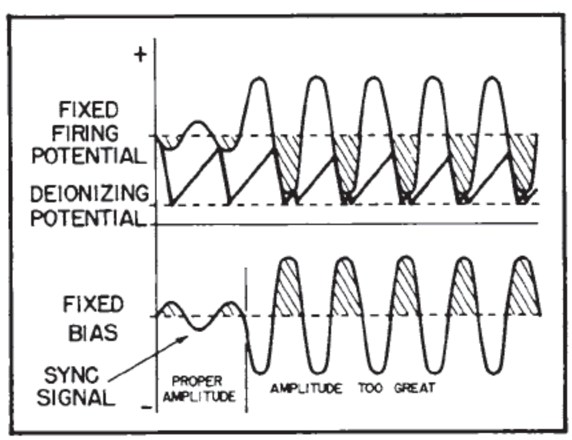

Figure 43-19 - Effect of large amplitude sync signal.

frequency of 500 cycles per second, one-half the signal frequency.

Due to the operating features of the thyratron oscillator it is possible to apply too little or too much synchronizing voltage to the tube. If too small a synchronizing signal is applied, the firing potential will not be lowered sufficiently to induce reliable triggering on each sweep, thereby causing jitter in the sweep pattern.

If too large a sync voltage is applied to the thyratron, severe distortion of the screen pattern can result. The reason for this is shown in Figure 43-19. The first cycle of operation shows normal conditions and proper sync amplitude. The remaining cycles illustrate the effects of over synchronization. Notice, that as the sync amplitude is increased, the firing potential is lowered to such an extent as to cause the tube to fire twice during the same alternation of sync voltage. Thus, as the positive alternation of the sync signal begins, the thyratron is triggered causing the sweep to commence. Before the sweep can trace very far across the screen the firing potential is reached again, initiating retrace and the start of a second and longer sweep during the same alternation of the sync signal.

To properly set the level of the sync voltage, the oscillator should be adjusted to a frequency slightly lower than the desired sweep frequency with no sync applied. Then, just enough sync should be applied to lock in the pattern.

A comparison of the thyratron sawtooth generator to the neon tube sawtooth generator shows the thyratron to have some decided advantages. Of the greatest importance is the fact that the thyratron has a control grid and can be locked to a synchronizing voltage. Additional advantages stem from the fact that the thyratron has a large thermionic cathode allowing higher plate currents (more rapid discharge) and a more stable ionization potential.

Q7. How does the thyratron tube differ from the neon tube?

Q8. When the bias in a thyratron sawtooth generator is increased, what happens to: output, amplitude, frequency, linearity, and the percent of charge curve used?

Q9. How is the natural frequency normally adjusted in the thyratron sawtooth generator?

Q10. What is the purpose of synchronizing the thyratron sawtooth generator?

Q11. What is the value of the natural frequency of the thyratron sawtooth generator, in comparison to the desired output frequency, when using synchronization?

Q12. If a synchronized thyratron sawtooth generator was required to produce sawtooth waveforms at a 400 cps rate, what sync frequencies could be used?

Q13. When would over synchronization occur?

Q14. If pulses are used as sync triggers, what polarity should they be?

43-4. Hard Tube Sawtooth Generator

In certain applications it is necessary to have a given amount of time delay between the end of retrace and the start of the next sweep. Although this type of operation is difficult to attain using gas tubes, it can be readily accomplished with vacuum tubes. This vacuum tube sweep circuit is called a HARD TUBE SAWTOOTH GENERATOR. (This name is derived from the early days of electronics when a vacuum tube was referred to as a "hard" tube and a gas tube was called a "soft" tube.)

Quantity	Frequency	Amplitude	Linearity
Increase R	Decrease	No Change	No Change
Increase C	Decrease	No Change	No Change
Increase B+	Increase	No Change	Improved
Increase Bias (more negative)	Decrease	Increased	Poor

CHART I

Chart I has been included to aid in summarizing the characteristics of the thyratron sawtooth generator. For example, the chart shows that an increase in B+ (plate supply voltage) causes an increase in oscillator frequency, no change in sawtooth amplitude, and improved linearity.

The schematic diagram of a hard tube generator is shown in Figure 43-20. Notice, that this circuit has an appearance somewhat similar to the thyratron generator. The sawtooth voltage is developed across sawtooth forming capacitor C_2. To develop the output waveform, capacitor

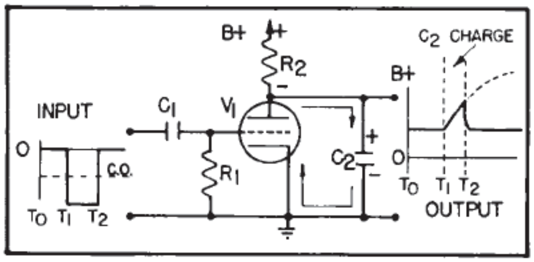

Figure 43-20 - Hard tube sawtooth generator

C_2 charges through R_2 for a given period of time, and then discharges through the tube. The period of time during which the capacitor charges is determined by the signal applied to the grid. This signal is a rectangularly shaped negative pulse called a GATING PULSE. One sawtooth of voltage is developed each time the gating pulse is applied to the grid. Since an input signal must be applied to the circuit in order to obtain an output, the hard tube generator is a wave shaping circuit and not an oscillator.

Before the application of a gating pulse to the grid of the tube in Figure 43-20 the grid to cathode potential is zero volts. This permits a relatively large plate current to flow, dropping plate voltage to a low value. Since capacitor C_2 is connected directly across the tube it will charge to the same voltage as appears across the tube.

At time T_1 the gating pulse is applied to the grid of V_1. At this instant the grid of the tube is driven highly negative cutting off plate current. In the absence of C_2 the plate voltage would rise immediately to the value of the supply voltage. However, since C_2 is connected across the tube, the plate voltage must follow the exponential charge curve of the capacitor. If the tube did not come back into conduction until after five time constants, C_2 would charge along the dotted curve to approximately the value of B+. If the output sawtooth is to have a linear rise, the capacitor must not be permitted to reach full charge.

At time T_2 the gating pulse ends and the grid voltage is brought back to zero almost instantly. As the grid voltage rises above cut-off, plate current starts to flow and plate voltage attempts to drop. Were it not for C_2, the sudden increase in plate current would cause the plate voltage to drop immediately to the low value it had at time T_0. However, since C_2 must discharge through the internal resistance of the tube (shown by arrows in Figure 43-20), the drop in plate voltage follows an exponential curve.

If the internal resistance of the tube is much lower than the resistance of R_2, the discharge time constant will be very short as compared to the charge time constant and a reasonably good sawtooth wave will result.

Notice that the sweep portion of the sawtooth wave (the time C_2 is allowed to charge) is determined by the width of the input pulse. Therefore, the width of the input pulse is also a factor in determining the amplitude of the sawtooth wave (assuming RC remain constant). Likewise the frequency of the output is determined by the frequency of the input gate pulses.

With the duration of the negative gate pulse remaining constant, the amplitude of the output pulse is normally increased by decreasing R_2 or C_2 as shown in Figure 43-21.

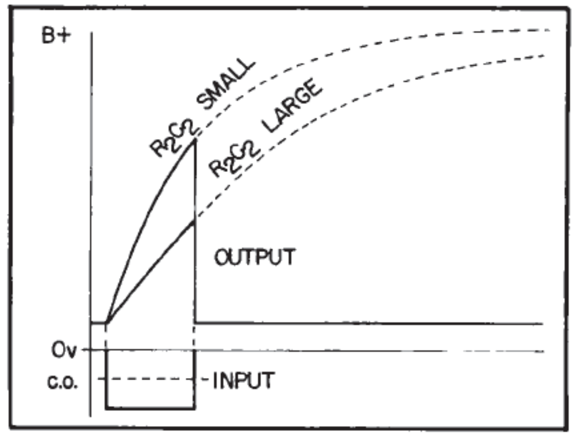

Figure 43-21 - Effects of varying R_2 and C_2 on output amplitude.

As R_2 and C_2 are made smaller, the capacitor charges faster (a shorter time constant), thus charging to a greater percentage of B+ voltage during the time of the input gate pulse. Therefore, the amplitude increases, but linearity decreases as shown in Figure 43-21.

If the duration of the input gate were to increase, the amplitude of the sawtooth waveform

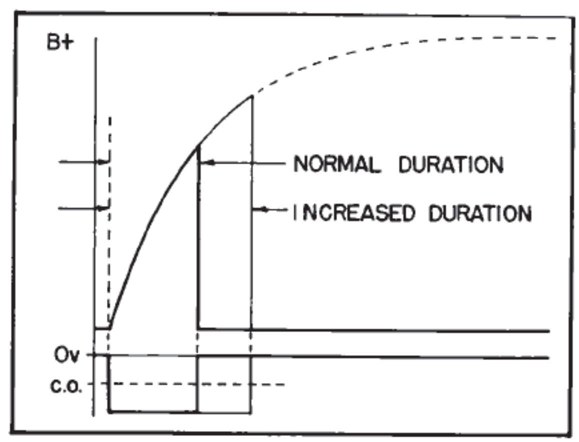

Figure 43-22 - Effects of changes in input duration on output amplitude.

A7. Its ionization potential can be controlled by its grid voltage (the neon tube has no grid).

A8. The amplitude increases, frequency decreases, linearity decreases. A greater percent of the charge curve is used.

A9. By varying the size of the resistance or capacitance used.

A10. To stabilize the output frequency.

A11. The natural frequency is slightly lower.

A12. 400 cps, 800 cps, 1200 cps, 1600 cps, etc.

A13. When using a sine wave sync signal of very large amplitude.

A14. They should be positive.

---

would increase and linearity would decrease as shown in Figure 43-22.

The output amplitude is often required to stay constant when input duration is increased as was done in Figure 43-22. To maintain constant amplitude, R_2 or C_2 may be increased the proper amount so that C_2 would charge more slowly.

In actual practice the time constant of R_2C_2 is usually very long so that C_2 charges for a small portion (percent) of the charge curve as shown in Figure 43-23. This provides very good linearity.

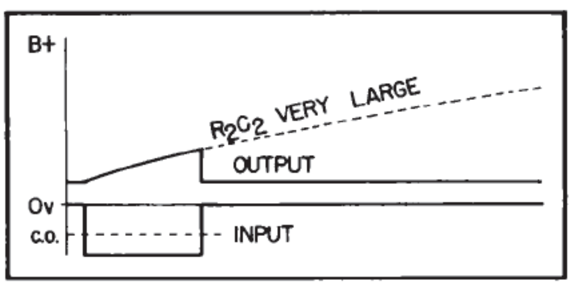

Figure 43-23 - Obtaining a high amount of linearity.

The low output amplitude is not a real disadvantage in this case because the horizontal amplifiers in the oscilloscope will provide sufficient amplification. However, the high degree of linearity is better than that which could be obtained from the thyratron or neon tube sawtooth generator.

Q15. Is the hard tube sawtooth generator free running? Why?

Q16. What type of trigger is used in the hard tube sawtooth generator?

Q17. How would output amplitude of the hard tube sawtooth generator normally be adjusted?

Q18. How can linearity of the sawtooth developed by the hard tube sawtooth generator be improved?

MULTIVIBRATORS

In the discussion on the hard tube sawtooth generator a square wave was required to trigger the circuit into operation. This square wave is usually obtained from a circuit called a MULTIVIBRATOR.

Multivibrators are divided into three catagories: BI-STABLE, MONO-STABLE and ASTABLE, or FREE RUNNING. The bi-stable multivibrator is so called because it has two stable conditions of operation and requires an input or trigger in order to change from one condition to the other. The mono-stable multivibrator is so called because it has one stable condition of operation and a temporary condition or state of operation. When triggered by an input, it switches from its normal stable condition to the temporary condition and then reverts to its stable condition. The astable or free running multivibrator requires no input and continually switches from one of its two operating conditions to the other and back again at a given rate. These circuits will be discussed in the order listed above.

43-5. Eccles-Jordan Multivibrator

The basic principles of a bi-stable multivibrator can be easily established if the action of the ECCLES-JORDAN circuit (sometimes refered to as a FLIP-FLOP or START-STOP multivibrator) is understood. This circuit, shown in Figure 43-24, uses direct coupling between the plates and grids of the two tubes and features two quiescent points. One quiescent point is established when V_1 is conducting and V_2 is cut-off, and the other occurs when V_2 is conducting and V_1 is cut-off.

This circuit essentially consists of two identical halves. $R_1 = R_2$, $R_3 = R_4$, $C_1 = C_2$, $R_5 = R_6$, and V_1 is the same as V_2. A negative bias level is established by bias supply E_{cc}. The output signal appears between the plate of V_2 and ground. The input is applied in series with the grid bias supply to the junction of C_1 and C_2. The function of the circuit components are as follows: R_1 and R_2 serve as plate load

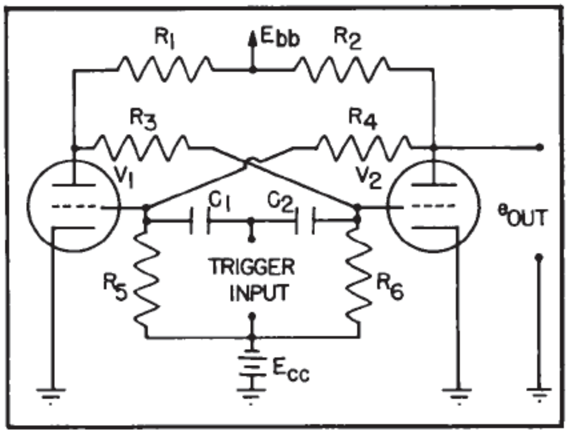

Figure 43-24 - Eccles-Jordan bi-stable multivibrator.

resistors, C_1 and C_2 are coupling capacitors for the input signal or trigger, R_3 and R_4 act as coupling resistors to couple a change in plate voltage of one tube to the grid of the other tube, R_5 and R_6 are grid leak resistors.

To begin the analysis of the Eccles-Jordan bi-stable multivibrator it will be assumed that no signal or trigger is present at the input. Since the conditions for both tubes are identical, it would appear that when plate voltage is applied both tubes would conduct equally well and no resultant action would take place. However, due to slight manufacturing tolerances and other factors, it is very difficult to obtain two circuits which are identical in every respect. In the operation of multivibrator circuits this is fortunate because many of these circuits rely on these slight differences to begin their operation. In other words, when plate voltage is applied, both tubes will begin to conduct, but one of the tubes will always conduct slightly more than the other. The significance of this action will be pointed out later in the analysis.

In order to further simplify the analysis of the Eccles-Jordan circuit it has been redrawn in Figure 43-25. Notice that two switches, S_1 and S_2, have been inserted in the cathode leads of the tubes. These switches are for purposes of explanation only and would not appear in a practical circuit.

With both cathode switches open, the circuit appears as two resistive voltage dividers connected across a source composed of E_{bb} and E_{cc} in series. One voltage divider is formed by the series combination of R_6, R_3, and R_1. In parallel with this is the other voltage divider formed by the series combination of R_5, R_4, and R_2. The voltage distribution is shown for only one voltage divider in Figure 43-25, however, it should be realized that the same voltage distribution also applies to the other voltage divider. Notice that the voltage drop across each grid resistor is 51 volts. This drop is in opposition to the 50 volts applied by E_{cc}. Therefore, the grids of V_1 and V_2 are 1 volt positive with respect to ground (cathode). Taking into account the 200 volt drop across the load resistors, the plate voltage of each tube will be 150 volts.

The operation of the circuit can be examined by observing the events which occur during the transient period, just prior to reaching a stable condition. If S_1 and S_2 are closed simultaneously, the positive grid potentials applied to the grid of each tube will cause nearly equal currents to rise in the two tubes. For purposes of explaination it will be assumed that the current rise in V_1 occurs at a slightly greater rate than the current rise in V_2. The increased plate current that flows in V_1 causes the voltage drop across R_1 to be larger than the voltage drop across R_2. This lowers the plate voltage of V_1 below the plate voltage of V_2.

Since V_1, acting as one branch, and the series combination of E_{cc}, R_6 and R_3, acting as a second branch, comprise a parallel circuit, the sum of the voltages across E_{cc}, R_6 and R_3 must be the same as the plate voltage of V_1. Thus, the decreased voltage at the plate of V_1 causes a reduction in the positive voltage at the grid of V_2.

The reduction in positive potential at the grid of V_2 acts as a negative-going input signal to V_2, causing its plate current to decrease. The reduction of plate current through V_2 causes the drop across R_2 to be less, permitting the plate voltage of V_2 to rise.

The rise in positive potential at the plate of V_2 allows the voltage across R_5 (and R_4) to increase. This appears as a positive-going input signal to V_1, further reinforcing the rapid increase in current through V_1.

It can be seen that the above action is regenerative and will continue until V_2 is driven into cut-off and V_1 is conducting heavily. Once this condition or state is reached, no further changes in circuit conditions will occur and the circuit is said to be in one of its two stable states. The circuit will remain in this stable state indefinitely, or, until some external signal is applied to cause the circuit to switch to the second of its two stable states. The circuit would be said to be in its second stable state when V_1 is cut-off and V_2 is conducting heavily.

In describing the succession of events during the transient period, the actions were described in a step-by-step manner. It must be pointed out, however, that these changes occur almost instantaneously (a fraction of a micro second). It should also be realized that in starting the circuit EITHER tube could be the one driven to maximum conduction, depending

A15. No. It must be triggered.

A16. A negative gate pulse of the same width as the desired output sawtooth waveform and large enough in amplitude to cut the tube off.

A17. By varying the resistance or capacitance.

A18. By using a large resistor and capacitor.

---

on the random conditions existing when the switches are closed.

To cause an abrupt transition from one stable state to another, a pulse or trigger is applied to the circuit.

Either a positive or negative pulse of sufficient amplitude will cause a change in the circuit conditions. The two capacitors between the grids of the tubes and the trigger input terminals isolate the grids from one another and provide coupling of the input trigger to both grids simultaneously. Assume that a negative trigger is applied to the grids of V_1 and V_2. This trigger will be coupled to the grid of V_2 as a negative signal, but will have no effect because V_2 is cut off. However, the trigger is also coupled to the grid of V_1. A negative signal applied to the grid of V_1 will cause a reduction in the plate current passed through the tube. This reduction in plate current will reduce the voltage drop across R_1, thereby, raising the plate voltage of V_1. This increasing plate voltage is coupled to the grid of V_2 as a decrease in the negative bias. This brings the tube out of cut-off and V_2 begins to conduct. The voltage drop across the plate load resistor (R_2) of V_2 increases, lowering the plate voltage of V_2, which is coupled to the grid of V_1 as a less positive potential. The decreasing voltage across R_5 drives V_1 toward cut-off. Decreasing the conduction of V_1, raises its plate voltage further, which in turn causes the conduction of V_2 to increase.

This progressive action (acting almost instantaneously) forces the switching of the circuit from one stable condition to the other. The circuit will now remain in the condition of V_2 conducting and V_1 cut-off until another trigger is applied. Consequently the circuit will change from one stable state to the other each time a trigger is applied.

The Eccles-Jordan bi-stable multivibrator would also work with a positive trigger. A negative trigger caused the current of the conducting tube to decrease, thereby, bringing the non-conducting tube out of cut-off. A positive trigger will directly change the bias of the non-conducting tube to bring it out of cut-off.

The output from the circuit may be taken

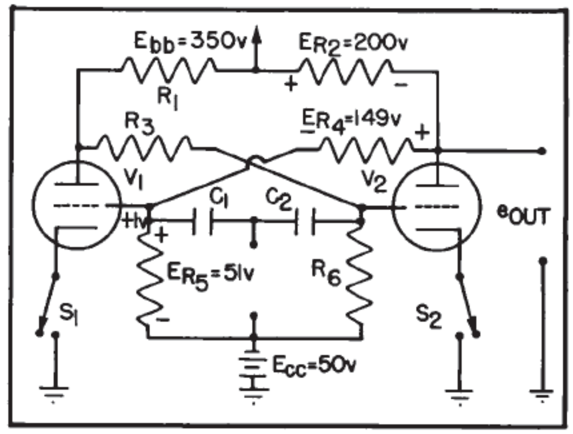

Figure 43-25 - Eccles-Jordan circuit and voltages.

between the plate and ground of either tube. The waveforms will be alike, but will appear to be displaced one alternation with respect to each other. Figure 43-26 illustrates the plate waveforms showing the time relationship between the trigger and the output pulses from each tube. Notice that before the first trigger is applied, the plate voltage (e_{b1}) of V_1 is low because V_1 is

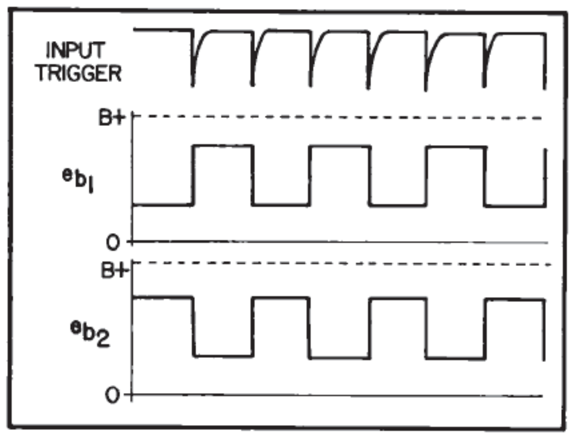

Figure 43-26 - Waveforms.

conducting, and the plate voltage (e_{b2}) of V_2 is high because V_2 is cut off. As the first trigger is applied, the waveforms indicate that the circuit switches conditions, because almost instantaneously, the plate voltage of V_1 becomes high (indicating V_1 cut-off) and the plate voltage of V_2 becomes low (indicating V_2 conduction).

Each additional trigger that is applied to the circuit will cause the circuit to switch states. Thus, if a continuous train of equally spaced pulses is applied to the input, a square wave will be developed at the plate of each tube. Pulses applied to the circuit at random intervals will produce a series of positive and negative

alternations having uneven lengths.

Q19. Could a train of alternately positive and negative pulses be used to trigger an Eccles-Jordan circuit?

43-6. Mono-stable Multivibrator

In the Eccles-Jordan circuit, the changes that occur at the plate of one tube are coupled to the grid of the other tube by resistors which link these respective elements. A signal can also be coupled from one stage to another by connecting the cathodes of the two tubes together. As the name implies, this type of coupling is used in the cathode coupled multivibrator.

Cathode coupled multivibrators, like other multivibrators, can be classified as free running if they provide a continuous output without an input, or, as "driven" if an input pulse is required in order to obtain an output. The circuit to be discussed in this section is a MONO-STABLE multivibrator and must be driven by an input pulse.

One type of mono-stable multivibrator is shown in Figure 43-27. Notice, that the plate current of both tubes must flow through the common cathode resistor (R_k). Since the grid resistor for V_1 is connected to ground, the voltage across R_k acts as the bias on V_1. The grid resistor for V_2 connects directly to the cathode of V_2, therefore, V_2 operates at zero bias.

When no driving pulses are applied to the grid of V_1, the circuit will remain in its single stable state. The reason for this can be made clear by considering the way in which the voltage across the common cathode resistor affects the operation of the circuit. When plate voltage is first applied to the circuit in Figure 43-27, both tubes begin to conduct. The combined plate current from the two tubes develops a voltage across resistor R_k as shown. This voltage forms the bias for V_1 but in no way controls the plate current through V_2.

As plate current rises in V_2 it increases the voltage drop across R_k, reducing the plate current of V_1. The decrease in plate current through V_1 causes the plate voltage of V_1 to increase. Because of the rise in plate voltage C_2 begins to charge through R_k, R_2, and R_3. The positive voltage developed at the grid of V_2 causes a further increase in the plate current of V_2 and also causes grid current to flow, which rapidly charges C_2. The greatly increased plate current through V_2 drives V_1 far into cutoff by virtue of the large bias voltage the plate current of V_2 produces across R_k.

When C_2 has completed its charge, no more current will flow through the series path composed of R_2, C_2, and R_3. With no current flow-

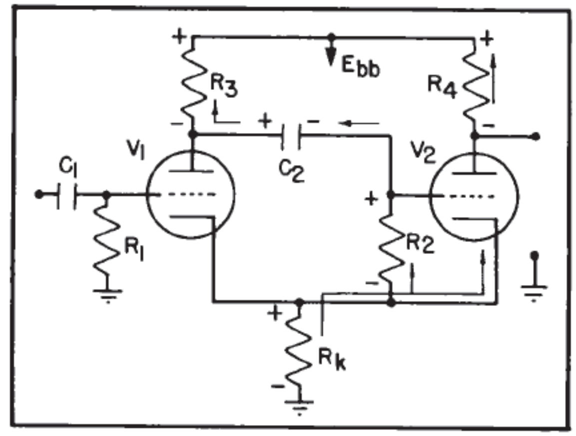

Figure 43-27 - Cathode coupled mono-stable multivibrator.

ing through R_2, the grid voltage of V_2 will decrease to zero (same potential on the grid and cathode). However, the characteristics of V_2 are such that zero bias will cause sufficient plate current flow through R_k to maintain the cut-off bias condition of V_1.

The condition of V_1 cut-off and V_2 conducting is the normal condition of the circuit in its stable state.

Because V_1 is normally cut off, only positive pulses can be used to trigger the circuit. Upon the application of a positive trigger, of sufficient amplitude to raise the grid voltage above cut-off, the tube will begin to conduct. The conduction of V_1 causes its plate voltage to decrease. When the plate voltage of V_1 decreases, C_2 will attempt to equalize its charge by discharging through R_2 and tube V_1 as shown by the arrows in Figure 43-28. This attempted discharge will cause a voltage to be developed across R_2 with the polarity shown. The result of this negative grid voltage is to drive V_2 into cut-off. With V_2 cutoff only the plate current of V_1 flows through

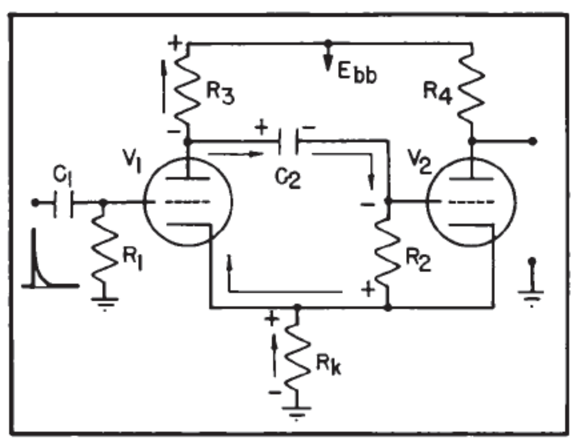

Figure 43-28 - Discharge path for C_2.

A19. Yes, since the pulses are applied to both grids either polarity will trigger the circuit.

R_k. Since the maximum plate current through V_1 is lower in value than the maximum plate current through V_2 (due to different biasing), the voltage across R_k will be at its minimum value during the time V_2 is cut off. As long as V_2 is cut off, V_1 will conduct. Since the negative voltage which maintains V_2 in cut-off is caused by the discharge of C_2, this voltage will decay at an exponential rate, as C_2 equalizes its charge. Therefore, the time V_2 remains cut off is governed by the R_2C_2 discharge time constant (the plate resistance of V_1 must be added to the resistance of R_2). As the grid voltage of V_2 rises above cut-off, the tube will again begin conduction.

As soon as V_2 begins to conduct, the voltage drop across the cathode resistor, R_k, will cause tube V_1 to cut off. After capacitor C_2 charges, the plate current through V_2 will reduce to its normal level, and the circuit will again be in its stable condition.

The waveforms in Figure 43-29 illustrate the entire operation of the cathode coupled monostable multivibrator. From time zero (T_0) to time one (T_1), the waveforms indicate the following conditions:

The plate voltage of V_1 (e_{b1}) is equal to B plus, indicating V_1 is cut off.

The plate voltage of V_2 (e_{b2}) is at some value between B plus and zero, indicating V_2 is conducting.

The grid voltage waveform (e_{g2}) of V_2 is the voltage measured between GRID AND CATHODE and is zero volts because the grid and cathode are at the same potential during this period. The dotted line on this waveform represents the value of negative grid voltage necessary to drive V_2 into cut-off.

The cathode voltage (e_k) of the tubes, as measured across R_k, is at some relatively high value of voltage (possibly 20 volts, although this value will vary greatly with tube types). The dotted line in this waveform indicates the value of positive voltage necessary on the cathode of V_1 (with zero grid voltage) to cut the tube off. The cathode voltage (e_k) being greater than this value indicates that V_1 is cut off during this period.

At time one (T_1) the first trigger is applied to the grid of V_1. Almost instantaneously the circuit changes from its stable operating condition to its temporary operating condition.

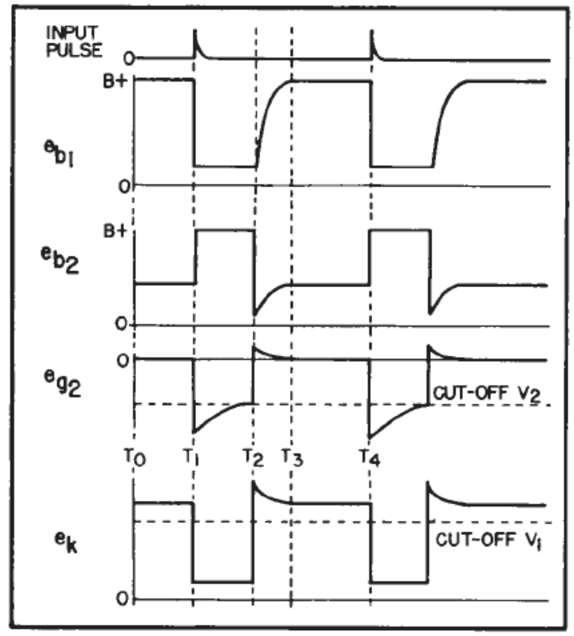

Figure 43-29 - Waveforms for the mono-stable multivibrator.

V_1 begins conducting, as indicated by the decrease in e_{b1}.

V_2 cuts off, as indicated by the increase in e_{b2}.

The discharge of C_2 applies a large negative voltage to the grid of V_2 (driving it below cut-off), as indicated by the drop in e_{g2}. The fall of e_k below the V_1 cut-off line indicates V_1 conducting. It also indicates that, since e_k decreased, the relatively large plate current of V_2 is absent.

From time one (T_1) to time two (T_2) the grid voltage e_{g2} rises towards cut-off in an exponential manner as C_2 discharges. At time two (T_2) the grid voltage of V_2 reaches the cut-off value and the circuit changes from the temporary operating condition back to its stable operating condition.

The time T_2 to T_3 (which has been greatly expanded for purposes of explanation) shows the various actions occuring due to the exponential charge of C_2.

From T_3 to T_4 the circuit remains in its stable operating condition. At T_4 the second trigger is applied, and the sequence of operations just explained will repeat themselves. Thus, a positive output pulse is generated for each input trigger.

The duration (width) and amplitude of the output waveshape may be altered by varying the supply voltage or circuit components in the following manner:

(1) Increasing C_2 or R_2 will increase the duration of the output pulse, but, will not effect the amplitude. The duration of the pulse is increased because the RC discharge time constant is increased and it will take longer for V_2 to come out of cut-off.

(2) Decreasing C_2 or R_2 will decrease the duration of the output pulse because the RC discharge time constant is decreased.

(3) Increasing the supply voltage E_{bb}, will increase both the output pulse duration and amplitude. The pulse duration is increased because there will be a larger change in V_1's plate voltage, which is coupled to V_2 as a larger grid voltage change. The pulse amplitude is increased because there will be a larger change in V_2's plate voltage.

(4) Decreasing the supply voltage E_{bb} will decrease both the pulse width and amplitude.

(5) The frequency of the output pulse is unaffected by component or supply variations. An output is obtained only when an input is applied.

Q20. Why is it preferable to apply the trigger pulse to the normally cut-off tube, especially when the trigger generator has a low or variable internal impedance?

Q21. What determines the amount of time that the normally cut-off tube of a mono-stable multivibrator will remain in the conducting state?

Q22. What waveform would be present on the grid of the normally cut-off tube of a mono-stable multivibrator when no trigger pulses are applied?

43-7. Free Running Multivibrator

In this section the operation of a FREE RUNNING cathode coupled multivibrator will be examined. As stated, free running means that no trigger is required to initiate the switching of the circuit from one state of operation to the other.

Figure 43-30 illustrates a free running cathode capacitor coupled multivibrator and the circuit wave-forms. When B+ is applied to the circuit, tube V2 will conduct harder than V_1. This can be seen by the fact that the grid of V_1 has a zero potential, while the charging current of C_2 (passing through R_2) applies a positive potential to the grid of V_2. Figure 43-31 shows the charge paths for C_1 and C_2. The charge path of C_1 is shown by the dotted arrows and the charge path of C_2 is shown by the solid arrows.

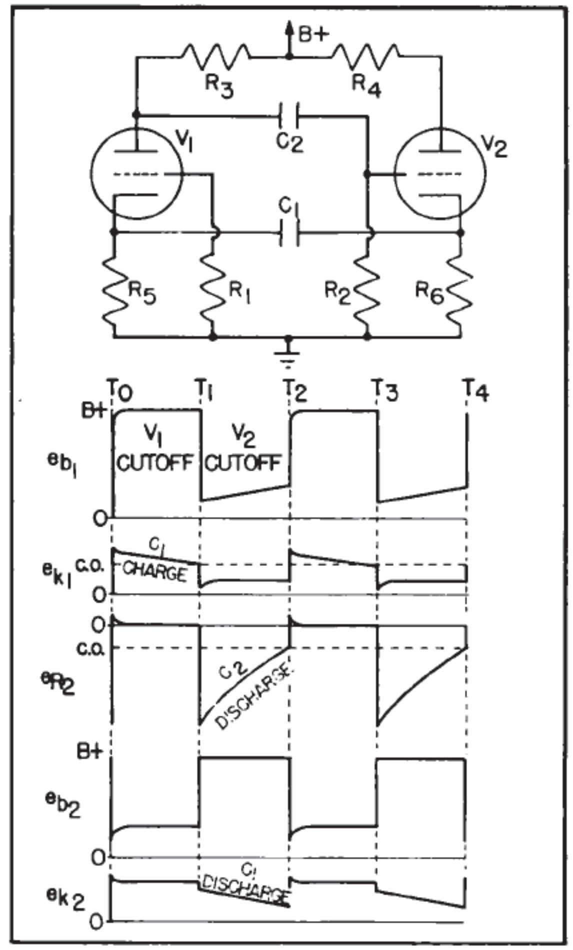

Figure 43-30 - Free running cathode capacitor coupled multivibrator.

The plate current of V_2 causes a voltage drop across the cathode resistor R_6, which is positive at the cathode end of the resistor. This potential causes C_1 to charge in the direction shown in Figure 43-31. The charging current of C_1 causes an additional drop across the cathode resistor, R_5, of V_1. Since the grid of V_1 is at zero potential, the positive voltage drop across R_5 drives V_1 into cut-off.

The circuit is now in a state of operation as depicted by the waveforms in Figure 43-30 between time zero (T_0) and time one (T_1). Notice that the plate voltage of V_1 (e_{b1}) is almost equal to B+, indicating V_1 cut-off. The cathode voltage of V_1 (e_{k1}) is more positive than the cut-off value. As C_1 assumes a charge it draws less current through R_5 and the cathode voltage, e_{k1}, will decrease towards the cut-off value. The grid voltage of V_2, as shown by the waveform e_{R2}, rapidly falls to zero as C_2 assumes its charge.

A20. When the trigger generator connects to the grid of the normally cut-off tube it has almost no adverse effects on the time constant of the coupling capacitor and grid leak resistor, providing more stable operating conditions.

A21. The RC time constant of the coupling network and the amount of change in e_{b1}.

A22. No waveform, since the grid would remain at zero volts with respect to ground.

At time one (T_1) the value of cathode voltage e_{k1} is no longer positive enough to keep V_1 cut-off. As V_1 begins to conduct, its plate voltage (e_{b1}) decreases. This decrease is coupled, by

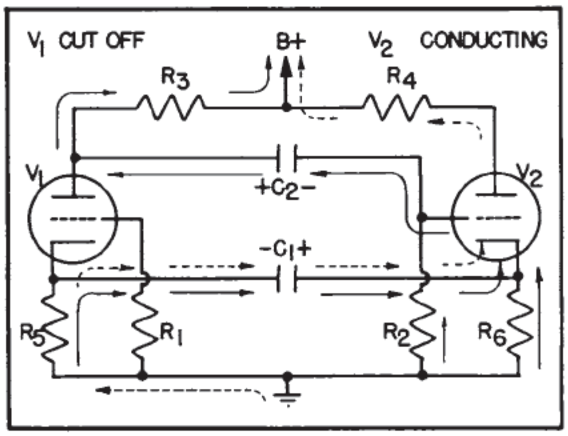

Figure 43-31 - Charge path of C_1 and C_2.

C_2, to the grid of V_2, driving it negative, as shown by e_{R2}. This negative potential drives V_2 into cut-off. The decrease in the potential across R_6 (shown by the slight drop in e_{k2} at T_1) causes C_1 to begin discharging. The discharge path of C_1 and C_2 is shown in Figure 43-32. The dotted arrow represents the discharge path of C_1 and the solid arrow represents the discharge path of C_2. The discharge of C_1 causes the potential across R_5 to be reduced, effectively reducing the bias of the tube, thereby increasing its conduction.

As C_2 discharges the grid potential of V_2 will approach the cut-off value of the tube in an exponential manner. During the time T_1 to T_2 the circuit will be operating with V_1 conducting and V_2 cut-off. At time two (T_2) the potential at the grid of V_2 will equal the cut-off value of the tube, as shown by waveform e_{R2}, and V_2 will come out of cut-off. The cycle of operation just completed will now repeat itself. The time of one cycle of operation is the cut-off time of V_1 plus the cut-off time of V_2.

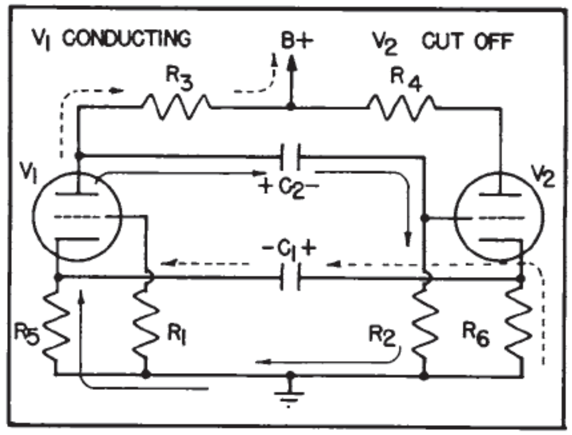

Figure 43-32 - Discharge path of C_2 and C_1.

Tube V_1 was cut off by the charging current of C_1 through R_5, V_2, and R_4 as shown in Figure 43-31.

Tube V_2 is cut off by the discharge currents of C_1 and C_2. C_1 discharges through V_1, R_3 and R_6. C_2 discharges through R_2, R_5 and V_1. Increasing any resistance in the charge path of C_1, or any resistance in the discharge path of C_1 or C_2 (except R_4) will decrease the frequency of the output. The output may be taken from either plate, but is normally taken from the plate of V_2.

Increasing R_4 causes a lower voltage to be developed across R_6 when V_2 conducts. When coupled to the cathode of V_1 by C_1 this voltage E_{R6} does not drive V_1 as far below cut-off. Thus, the cut-off time of V_1 is shorter and frequency is increased. The only resistor in the circuit that has no effect on the output frequency is R_1 because it merely returns the grid of V_1 to ground. Resistor R_2 is normally used to vary the frequency because it produces a large change in frequency without changing the amplitude of the plate waveforms. This circuit may also be synchronized to improve frequency stability.

Q23. What is the action of the cathode coupling capacitor during the time that V_1 is cut off?

Q24. When the plate current of V_1 is maximum what value is the plate voltage of V_2?

Q25. What effect would an increase in the value R_3 have on the cut-off time of V_2?

Q26. Would the output be taken from the plate of V_1 or V_2 if the most rectangular waveform is desired?

PLATE COUPLED MULTIVIBRATOR

43-8. Free Running Plate Coupled Multivibrator

The basic FREE-RUNNING PLATE COUPLED MULTIVIBRATOR circuit is a simple two stage resistance-coupled amplifier, with the output of the second stage coupled back into the input of the first stage (Figure 43-33). Since each stage inverts the signal, a voltage change occurring at the grid of either tube will be amplified, inverted, and coupled to the grid of the other tube where it will again be amplified, re-inverted, and coupled back in phase to the grid from which it originated. The schematic of a conventional free running plate coupled multivibrator is shown in Figure 43-33.

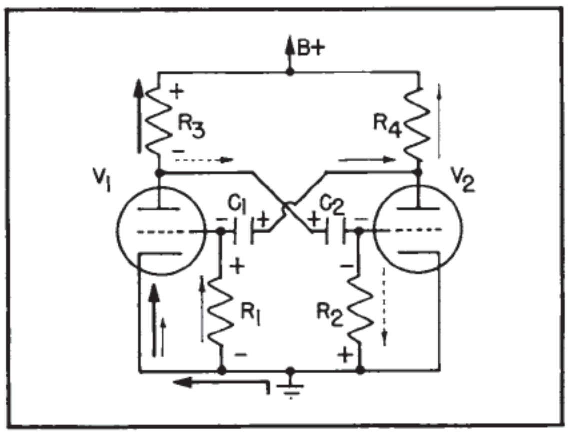

Figure 43-33 - Free running plate coupled multivibrator.

When the cathodes are heated and plate potential is applied, both tubes begin to conduct and capacitors C_1 and C_2 begin to charge with the polarities shown. Initially the plate currents of the tubes are nearly equal, however, there is always a slight difference in the circuits which results in an unbalanced condition. This unbalanced condition causes one tube to begin conducting more heavily than the other. This unequal conduction of the tubes brings about a cumulative or regenerative switching action, which, in this example, is assumed to end with V_1 conducting and V_2 cut-off. Although described as if it occurred slowly, this switching occurs with extreme rapidity (in less than a microsecond in a well designed multivibrator). This action is followed by a relatively long period in which the tubes are quiescent. During this interval one capacitor charges and the other capacitor discharges.

Assume that initially the plate current of V_1 begins to rise more rapidly than the plate current of V_2. The plate voltage of V_1 will begin to decrease (because of the increased drop across R_3). As V_1's plate voltage decreases, C_2 will begin to discharge. The discharge path, as shown by the dotted arrows in Figure 43-33, will be from the negative terminal of C_2, through R_2, V_1, and back to the positive terminal of C_2. This discharge will cause a negative potential to be applied to the grid of V_2, which will, in turn, cause a decrease in the tube current of V_2 and an increase in its plate voltage. An increase in the positive potential at the plate of V_2 will cause C_1 to increase its charge. The charge path for C_1, as shown by the light solid arrows in the illustration, will include R_4, the B+ supply, and the grid to cathode resistance of V_1 in parallel with R_1. This charging current will increase the positive potential at the grid of V_1, and thereby increase the plate current of V_1 (heavy arrows).

This action is cumulative and will result in the cutting off of V_2.

The circuit is now in one of its two semi-stable states of operation, and will remain so as long as V_2 is in a cut-off condition. The negative potential on the grid of V_2 will decrease towards the cut-off value at an exponential rate as C_2 discharges. At the instant the cut-off value of V_2 is reached and it begins to conduct, the actions just discussed will be reversed and switching will result in the circuit changing to its second semi-stable state of operation. During this state of operation, V_1 will be cut off and V_2 will be conducting. C_1 will be discharging through R_1 and V_2. C_2 will be charging, its path being the parallel combination of R_2 and the grid-to-cathode resistance of V_2, R_3, and the B+ supply. The plate coupled multivibrator circuit, shown in Figure 43-35, can be analyzed using the tubes characteristic curves and a load line. V_1 and V_2 of the circuit are actually contained within the same tube envelope, each being one-half of a 6SN7 dual triode tube. As described in the general operation of the circuit, the plate voltages of the tubes will vary from B+, when the tubes are cut off, to some lower value when the tubes are conducting. These values can be determined, and the plate voltage waveforms constructed, from the load line. Since the characteristics for both halves of the tube are identical, and the same value of load is used in both cases, a single set of curves and load line will suffice for the analysis. The curves and load line are shown in Figure 43-34.

The load line is constructed in the normal manner, with one point being plotted where plate voltage equals B+ (350 volts) and the other point plotted at 17.5 milliamps of plate current.

It is assumed that the circuit has been operating and at time one (T_1), in Figure 43-35, the switch from one operating state to the other has just occurred. At time one the V_2 section of the 6SN7 dual triode comes into conduction. The

A23. It will be charging.

A24. The plate voltage of V_2 will be equal to B+.

A25. The cut-off time would increase.

A26. The plate waveform of V_2.

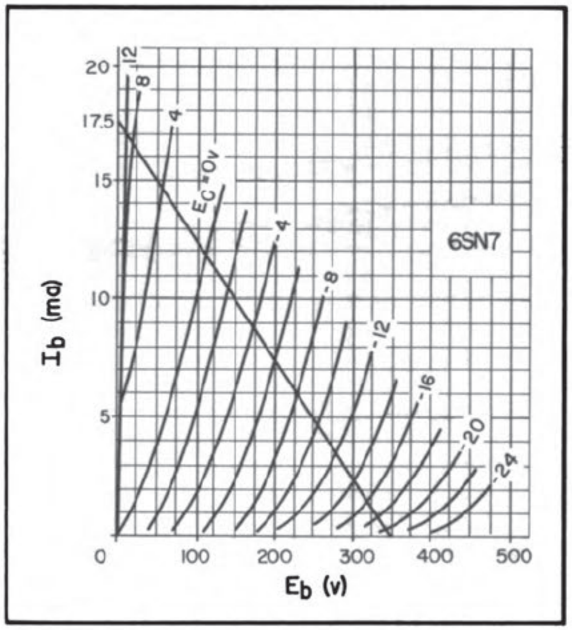

Figure 43-34 - 6SN7 curves and load line.

charging current of C_2, through the parallel combination of R_2 and the grid-to-cathode resistance of V_2, causes the grid voltage (e_{g2}) to increase to approximately 11 volts. Although the positive 11 volts grid curve does not appear on the characteristic curves (Figure 43-34) its position can be estimated as being near the positive 12 volt curve. With 11 volts on the grid, approximately 17 milliamperes of plate current will flow. A plate current of 17 milliamps through V_2 (at T_1) will cause a 340 volt drop across the plate load resistor R_4. This will cause the plate voltage of V_2 to fall to 10 volts, as shown by the e_{b2} waveform in Figure 43-35.

The fall of V_2's plate voltage from 350 volts to 10 volts represents a change of 340 volts. Since a capacitor (in a circuit containing resistance) cannot instantaneously change its voltage, this entire change is coupled through C_1 to grid resistor R_1. This is shown by the grid voltage waveform (e_{g1}) falling to a negative 340 volts at T_1. Although the negative 340 volts on the grid of V_1 causes the tube to cut-off, its plate voltage does not rise instantly to B+ because the charging current of C_2 causes a voltage drop across R_3.

Due to the relatively low value of resistance in its charge path, the charging time constant of C_2 will be fairly short (approximately 20 microseconds for this circuit). Thus, for all practical purposes, C_2 will cease to charge after five time constants, or approximately 100 microseconds. Time one (T_1) to time two (T_2) in Figure 43-35 represents 100 microseconds.

As C_2 assumes its charge, V_2's grid voltage decreases from 11 volts to zero volts, as shown between T_1 and T_2 for e_{g2}. During this time, the exponential decrease of C_2's charge current causes less voltage drop across R_3 and thereby, raises V_1's plate voltage until (at T_2) it equals B+. Notice that, during the period T_1 to T_2, V_2's plate voltage also increases, going from 10 volts to 110 volts. This is caused by the fact that, as the grid voltage e_{g2} falls to zero, the plate current decreases. The load line (Figure 43-34) shows that when grid voltage is zero, approximately 12 ma of plate current is flowing. This value of current causes 240 volts to be dropped across R_4, leaving 110 volts as plate voltage.

From the instant switching occurred and the grid of V_1 was driven 340 volts negative, C_1 discharges and the grid voltage (e_{g1}) begins decreasing towards the cut-off value. The relatively large resistance in the discharge path causes the discharge time constant to be fairly long, approximately 100 microseconds for this circuit.

From time two (T_2) until time three (T_3) the only change taking place in the circuit is that of the grid voltage e_{g1}, with the other voltages remaining in a quiescent state.

It can be seen from the load line (Figure 43-34) that the cut-off grid voltage for a 6SN7, with 350 volts plate potential is approximately -22 volts. When C_1 has been discharging for approximately 280 microseconds (2.8 time constants), the grid voltage of e_{g1} will have decreased to -22 volts.

At the instant the grid voltage equals cut-off (T_3), tube V_1 will begin to conduct and the switching action of the circuit will be initiated. It is seen by the nearly vertical lines on the waveforms, at T_3, that the switching action is practically instantaneous. However, in the following discussion this instant will be expanded to insure a more thorough understanding of the action. In order to accomplish this expansion, the action of the circuit will be halted immediately after cut-off is attained.

The waveforms (Figure 43-35) show that just previous to T_3 the circuit conditions are as follows:

The grid voltage of V_1 (e_{g1}) is at cut-off, -22 volts.

The plate voltage of V_1 (e_{b1}) is equal to B+, 350 volts.

The grid voltage of V_2 (e_{g2}) is at zero volts.

The plate voltage of V_2 (e_{b2}) is at 110 volts. Capacitor C_1 has discharged to 132 volts, thus 132 + (-22) = 110 volts (e_{b2}).

Capacitor C_2 is fully charged to 350 volts because the plate of V_1 equals 350 volts and the grid of V_2 equals zero volts.

The action of the circuit will now be examined when the grid of V_1 is one volt above cut-off (e_{g1} equals -21 volts). From the load line it is found that a -21 volts on the grid will cause a very small plate current (possibly 10 microamperes) to flow. This small current will cause a small drop across R_3 (possibly 0.02 volts,), which in turn lowers V_1's plate voltage by the same amount. This 0.02 volts change in V_1's plate voltage is coupled through C_2 to grid resistor R_2, causing a negative 0.02 volts at the grid of V_2. If an amplification of 10 is assumed for the tubes in this circuit, the 0.02 volts change at the grid will cause a 0.2 of a volt change in V_2's plate voltage. The slight increase in V_2's plate voltage will cause C_1 to draw a small charging current up through R_1. The change in V_2's plate voltage appears as a positive 0.2 volts on V_1's grid. This means that V_1's grid goes instantly from -21 volts to positive 0.2 volts, a change in grid voltage of 21.2 volts. Due to the amplification of the tube, this grid voltage change will appear at V_1's plate as a 212 volt change in plate voltage. This is a regenerative feedback action and will continue with the 212 volt change in e_{b1} being coupled to V_2's grid, driving it into cut-off.

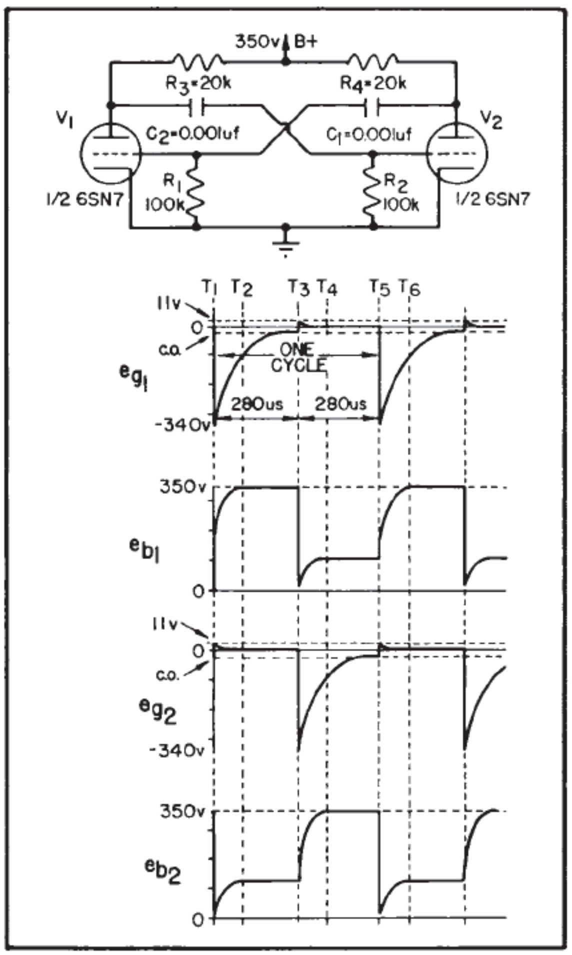

Figure 43-35 - Plate coupled multivibrator with waveforms as taken from an oscilloscope.

Due to this regenerative action, it can be seen that even the slightest change in the state (non-conducting to conducting) of the cut-off tube will result in an almost instantaneous switching of the circuit. The circuit is now in its second condition of operation, with V_1 conducting and V_2 cut-off.

The action of the circuit from T_3 to T_4 is the same as that described for T_1 to T_2, except the role of the components is reversed (where C_1 was discharging it is now charging, etc). The action of the circuit between T_4 and T_5 is the same as that described between T_2 and T_3.

At T_5 the voltage at the grid of V_2 reaches cut-off, and switching is again initiated.

Time one to time five represents one complete cycle of operation, taking approximately 560 microseconds. The frequency of operation of the circuit can be found by transposing equation (8-5) and inserting values.

$$t = \frac{1}{f} \qquad (8\text{-}5)$$

transposing: $f = \frac{1}{t}$

where: f = frequency in cps
t = time of one cycle in seconds

Insert values:

$$f = \frac{1}{560 \times 10^{-6}}$$

$$f = 1785 \text{ cps (approximately)}$$

Thus, the frequency of operation of the free running plate coupled multivibrator (Figure 43-35) is approximately 1785 cycles per second.

The output from this circuit is normally taken from either plate, although the grid waveform is sometimes useful.

The effects on circuit operation of increasing the value of various components is shown by the waveforms in Figure 43-36. Part A of the illustration shows the normal waveforms of the circuit when all comparable components are equal in value. Part B shows the waveforms (actually observed on the screen of an oscilloscope) of the circuit when the value of R_3, plate load resistor of V_1, is increased to 100k ohms. The time base has been changed in order that a single cycle of operation appears on the screen. The duration of the second alternation of all the waveforms in part B is approximately the same as the second alternation of the normal waveform. However, due to the alternation of the time base the second alternation appears smaller. Due to the increased resistance of R_3 the plate voltage of V_1 will experience a larger change between the zero bias and cut-off values. Thus, the amplitude of e_{b1} will be increased. The duration of the first alternation is longer than the second alternation, indicating that V_1 is conducting for a longer period of time than it is cut off. Notice the increase in the rounding of the leading edge, caused by the increased charging time of C_2. The long duration of the first alternation of e_{b2} indicates that V_2 is cut off for a longer period of time than it is conducting. A comparison of the two grid waveforms indicates that the grid of V_2 (e_{g2}) is driven further into cut-off than the grid of V_1, due to the larger change at the plate of V_1. Therefore, C_2 will discharge for a longer period of time until the grid voltage reaches the cut-off value of the tube, thereby holding V_2 cut-off longer than V_1. Since the sum of the two alternations is now longer than for normal operation, the frequency of the circuit will be decreased.

Part C of Figure 43-36 illustrates the waveforms observed when R_1, the grid resistor of V_1, is increased to one megohm. All other components have the same value as the normal circuit. The time base of part C is also altered, with the first alternation of the waveforms having the same duration as the normal waveform. Therefore, it can be seen that increasing R_1 has lengthened the duration of the second alternation considerably. The plate voltage waveform, e_{b1}, indicates that V_1 is cut off for a much longer period of time than it is conducting. Waveform e_{b2} indicates that V_2 is conducting for a longer period of time than it is cut off. Notice the increased rounding of the leading edge due to the increased charging time of C_1 (C_1 charges through the parallel path of R_1 and the grid-to-cathode resistance of V_1). Increasing R_1 increases the discharge time constant of C_1, thereby, applying a cut-off potential to the grid of V_1 for a longer period of time (as shown by the e_{g1} waveform). Since one alternation is longer than normal, the complete cycle will

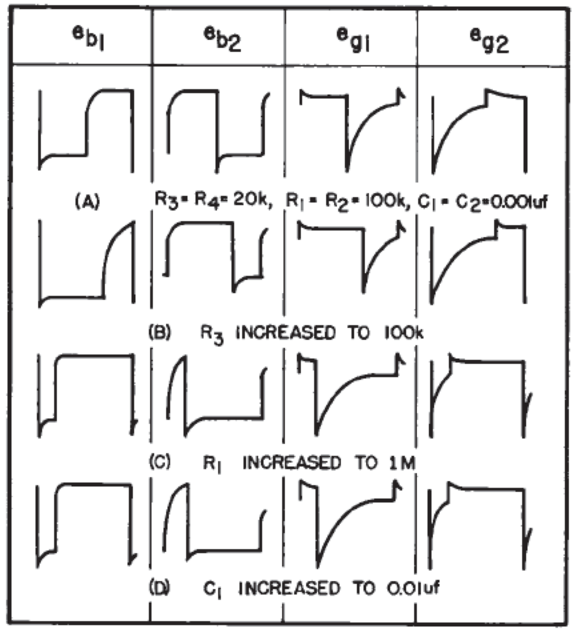

Figure 43-36 - Waveforms showing effect of increasing component values.

encompass a longer period of time. Thus, the frequency of operation will be lower than normal.

Part D of Figure 43-36 shows the waveforms observed when the value of coupling capacitor C_1 is increased to 0.01 microfarads. The effect of a larger capacitance is to increase the RC discharge time constant, with the same results as were obtained when the resistance was increased. Thus, the waveforms in part D will be the same as the waveforms in part C, and the same explanation applies.

The frequency stability of a free running multivibrator is rather poor. In order to achieve a better understanding of the manner in which supply voltage and component value variations effect the frequency stability Figure 43-37 will be used.

Part A of the figure shows the effect of a decrease in the value of either the grid resistor or the coupling capacitor on the frequency of operation. The heavy line shows the desired grid voltage waveform. Notice that the grid voltage approaches the cut-off value of the tube at a very shallow angle. At time three (T_3) it reaches the cut-off value and switching occurs. Due to the shallow angle of approach, slight variations in the RC discharge time can cause the cut-off value to be reached at some time other than the desired time. For instance, if the value of the grid resistor or coupling capacitor decreases for some reason, the RC discharge time will be

decreased. The light line in Figure 43-37A shows the waveform with the RC discharge time SLIGHTLY decreased. Notice that even the slight decrease in the RC time will cause the cut-off value to be reached at time two (T_2) rather than time three (T_3). The dotted line shows the waveform for a SLIGHT increase in the RC discharge time. This will cause the cut-off value to be reached at time four (T_4) rather than time three (T_3). Thus, a slight variation in the RC time will cause a relatively large variation in the duration of the alternation, resulting in poor frequency stability.

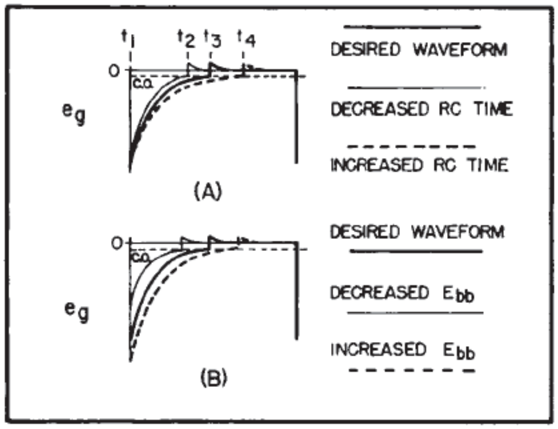

Figure 43-37 - Effect of voltage and component variation on frequency stability.

Part B of Figure 43-37 shows the effect of a varying supply voltage on the frequency of a free running multivibrator. The heavy line represents the desired waveform and T_1 to T_3 is the desired duration of the alternation. A decrease in the supply voltage will cause a lower charge on the coupling capacitor and a smaller change in plate voltage coupled to the opposite grid. This results in the grid being driven less negative during cut-off (shown by the light line in Figure 43-37B). The coupling capacitor will then discharge for a shorter period of time before reaching the cut-off value (time T_1 to T_2). The cut-off value will also decrease a slight amount but this will not change the operation a significant amount.

Increasing the supply voltage will cause a larger charge of the coupling capacitor and a larger change in plate voltage during switching. This will result in the grid being driven further negative, and a longer period of discharge before the grid voltage reaches cut-off. This condition is shown by the dotted line in Figure 43-37B. The cut-off value will be increased slightly in this case, but again will not significantly effect the operation. Increasing the supply voltage will increase the duration of the cut-off alternation, and thereby decrease the frequency of operation. The shallow angle of approach to cut-off will result in a slight change in supply voltage causing a relatively large change in frequency.

Q27. What would be the approximate cut-off voltage of the 6SN7 tube in Figure 43-35 if the supply voltage were lowered to 250 volts?

Q28. What determines the cut-off time of V_2 in the plate coupled multivibrator?

Q29. What determines the amplitude of each plate waveform in the plate coupled multivibrator?

43-9. Synchronization of Free Running Multivibrator

The various multivibrator circuits find extensive use in radar and test equipment. However, due to the poor frequency stability of free running multivibrators they are seldom used in this mode of operation, instead, they are synchronized with another frequency that forces the period of the multivibrator oscillation to be exactly the same as that of the synchronizing frequency. When a synchronizing signal is used, the multivibrator is said to be DRIVEN by the sync voltage.

Sine waves or pulses are generally used for synchronizing purposes, although waveforms of almost any shape could be used. Synchronization by means of sine waves will be considered first. The synchronizing signal may be injected in series with the cathode circuit or between the grid and cathode. Only synchronization with a grid signal will be considered in this chapter.

A standard free running plate coupled multivibrator, with provisions for applying a synchronizing signal, is shown in Figure 43-38. Notice that a sine wave voltage generator is connected between the grid and cathode of V_1. Switch S_1 provides a method of disconnecting the sync signal and allowing the multivibrator to be free running. The internal resistance of the generator (represented by R_i) must be relatively large in order to prevent it from shunting R_1 the input of V_1. The other components have the same values and functions as explained in the previous section.

It was determined in section 43-8, that the free running frequency of this circuit is approximately 1785 cycles per second. Normally the free running frequency is LOWER than the frequency of the synchronizing voltage, therefore, (in this discussion) the sync signal will have a frequency of 2500 cycles per second. Figure 43-39 shows the grid voltage and the sync volt-

A27. Approximately -14 volts.

A28. The time constant of the grid circuit of V_2, the value of the cut-off bias of V_2, and the change in the plate voltage of V_1 when it goes into conduction.

A29. The B+ value, the plate load resistor, and the type of tube used.

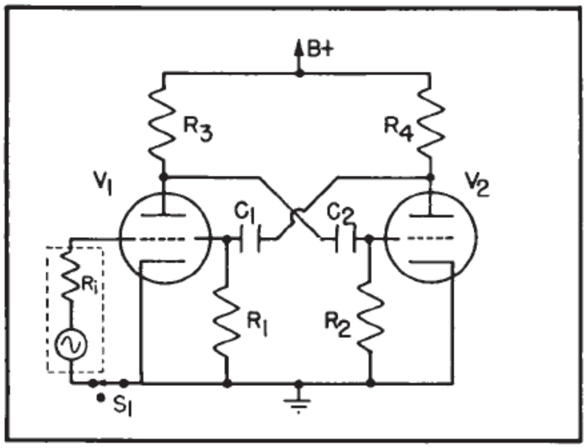

Figure 43-38 - Synchronized plate coupled multivibrator.

age waveforms of the circuit, and will be used to clarify the discussion.

In normal applications the amplitude of the sync signal is relatively small in comparison to the amplitude of the grid waveform (e_{g1}). However, in order to emphasize the triggering action and the effect on the shape of the grid waveform, the sync signal amplitude has been made fairly large.

It is assumed that switch S_1 is OPEN and that the circuit is free running. Therefore, the shape and duration of e_{g1} and e_{b1} (Figure 43-39) will be the same as discussed in section 43-8. Analysis of the circuit will commence at a time when V_1 is conducting and V_2 is cut-off. This is shown by the fact that from T_1 to T_2, the grid of V_1 is at zero volts and the plate voltage is low. At T_2 the normal switching action of the circuit is initiated and the grid of V_1 is driven far into cut-off and the plate voltage increases towards B+. From T_2 to T_3 the duration of V_1's cut-off alternation is determined by the R_1C_1 discharge time constant. At T_3 V_1's grid voltage reaches cut-off and normal switching action is initiated. At T_4 switch S_1 is closed and the sync signal is applied to the grid of V_1. At this time coupling capacitor C_1 has completed its charge and the grid potential is zero. At first glance it would appear that during the time T_4 to T_5 the positive sync voltage would cause the grid to assume a positive potential. However, due to a special action, called GRID LIMITING, the grid potential will remain at approximately zero volts. Grid limiting action can be explained by referring to the input circuit of V_1 (Figure 43-38). Notice that the generator, the grid-to-cathode resistance of V_1, and the internal resistance (R_i) of the generator, form a series circuit. As the sync voltage goes positive, grid current is drawn and is caused to flow in a counterclockwise direction in this series circuit. Since the internal resistance of the generator is VERY large in comparison to the grid-to-cathode resistance of the conducting tube, virtually all of the sync voltage is dropped across R_i on the positive half cycle. Thus, a very small percentage of the positive voltage appears between grid and cathode, and for all practical purposes the grid waveform remains at zero during this time.

At T_5 (Figure 43-39) the synchronizing voltage passes through zero and begins its negative half cycle. On the negative half cycle of the sync voltage, no grid current flows and virtually all of the sync voltage appears between grid and cathode, where it adds algebraically to the voltage produced across R_1. The resultant grid waveform will be the sum of these two voltages. Thus, at T_5 when the sync voltage becomes slightly negative it will cause V_1's grid to assume a slight negative potential. This will decrease V_1's plate current slightly and, thereby, initiate the switching action.

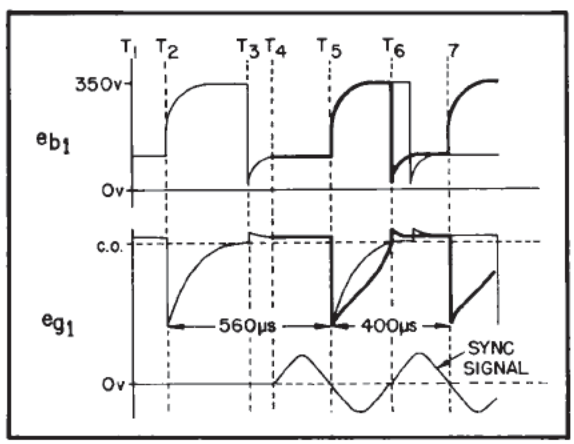

Figure 43-39 - Sine wave synchronization of the multivibrator.

The heavy lines in Figure 43-39 represent the resultant waveforms due to the addition of the sync voltage. The light line represents the waveforms as they would be with no sync voltage applied. Notice that from T_5 on, the light and

heavy waveforms do not coincide. Due to the effect of the negative alternation of the sync signal, the grid voltage is caused to approach cut-off at a steeper angle. It will be recalled that the shallow angle of approach to cut-off allowed small variations of component values, etc., to effect the frequency stability of the circuit. The steeper angle of approach is helpful in eliminating the effect of these variations. At T_6 the sync signal passes through zero and begins its positive alternation. The positive sync signal quickly forces the grid potential above cut-off and initiates the switching action before it normally would have occurred (as indicated by the light line waveform). From T_6 to T_7 the action is the same as explained between T_4 and T_5. At T_7 the sync signal again begins its negative alternation, causing a negative grid potential, decreasing plate current, and initiating switching action. It can be seen that shortly after the application of the synchronizing signal the period of the multivibrator is forced to be the same as a period of the sync signal. It can also be seen that use of a sine wave as a sync signal, allows the sync signal to control BOTH the initiation of conduction and the initiation of cut-off of the triggered tube. The waveforms of V_2 will be the same as those shown for V_1, except that they will be displaced along the time axis by a distance of one alternation (similar to Figure 43-35).

Although multivibrators can be synchronized with a sine wave voltage, a more accurate, and satisfactory, synchronization is obtained by the use of voltage pulses. These pulses may be either positive or negative, however, only positive pulses are considered in this chapter.

Figure 43-40 illustrates a free running plate coupled multivibrator which is synchronized by the application of positive pulses to the grid of V_1. A positive trigger pulse applied to the grid of a conducting tube has no effect on the action of the multivibrator (due to the grid limiting action explained previously). This is shown by the fact that pulses B and C, applied when V_1 is conducting, do not noticably effect the shape of the grid waveform.

However, when a positive trigger pulse is applied to a nonconducting tube, AND IS OF SUFFICIENT AMPLITUDE to raise the grid above cut-off, such as pulse D, the tubes are switched as current starts to flow in the tube which was formerly cut-off. Pulse D forces the tube into conduction just prior to point X, where it would have come into conduction naturally. This causes the negative alternation of e_{g1} to be shortened, thereby, narrowing the positive alternation of e_{b1}. The positive alternation of e_{g1} is unchanged, thus, the cut-off time of V_2 (negative alternation of e_{g2}) will remain unchanged. This results in the positive

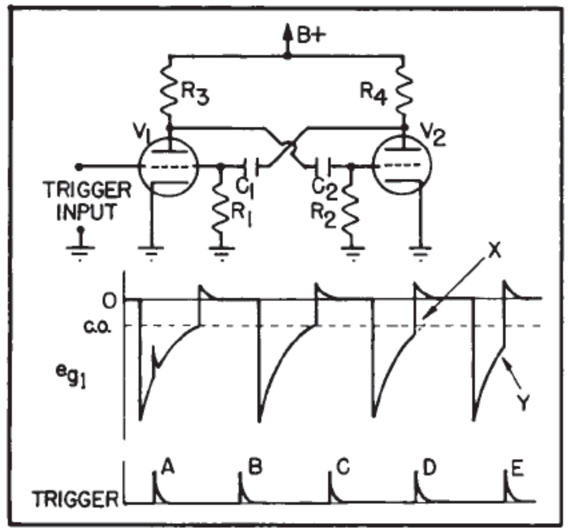

Figure 43-40 - Positive pulse synchronization of multivibrator.

alternation of e_{b2} remaining unchanged. In other words, the positive alternation of the triggered tubes plate waveform will be narrower than the positive alternation of the untriggered tubes plate waveform.

If the trigger pulse occurs at a time, such as pulse A, the amplitude of the pulse will not be sufficient to raise the grid voltage to the cut-off value and the switching action will not be initiated.

With the exception of the trigger pulse A, the grid waveform shown in Figure 43-40 is that of a free running multivibrator until pulse D arrives. Pulse D causes the period of the multivibrator to be shortened by an amount equal to the time between Pulse D and point X. In order for proper synchronization to take place the period of the multivibrator must be greater than the interval between pulses. Then the trigger pulses cause the multivibrator to switch earlier in the cycle than it would if free running. As a result, the grid has not reached cut-off by the time pulse E is applied. This, the frequency of the multivibrator is forced to be the same as the frequency of the trigger pulses, and the multivibrator will be switched consistently at a time represented by point Y.

It should be noticed, that while the sine wave synchronizing signal controlled both conduction and cut-off, the pulse synchronizing signal controls only the initiation of conduction.

Q30. Could positive synchronizing triggers be applied to V_2 instead of V_1?

A30. Yes. The sync pulses could be applied to either tube.

43-10. OS-8C/U Sweep Generator

The purpose of this section is to analyze the action of an actual SWEEP GENERATOR, utilizing the knowledge of sawtooth generators and multivibrators gained in the previous sections. The circuit chosen is the sweep circuit oscillator of the OS-8C/U oscilloscope. This circuit is basically a free running cathode coupled multivibrator, with the addition of a sawtooth forming capacitor across its output.

For purposes of explanation, a simplified schematic of the sweep circuit oscillator is shown in Figure 43-41.

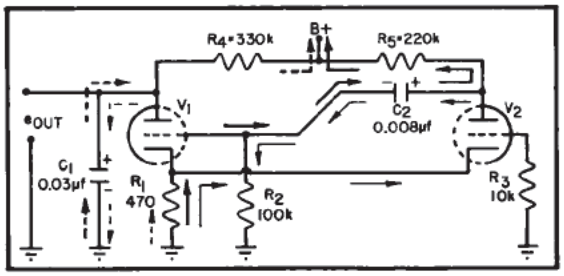

Figure 43-41 - Simplified schematic of OS-8C/U sweep circuit oscillator.

Notice that the circuit is similar in appearance to the monostable cathode coupled multivibrator. However, the small value of cathode resistor R_1, and the fact that BOTH grid resistors are returned to ground, allow the circuit to be free running.

The tube is a dual triode 6J6 (with V_1 representing one triode section and V_2 representing the other). C_1 functions as the sawtooth forming capacitor; C_2 is the coupling capacitor. C_1 will have a long charging time constant, due to the large RC product of its charging path (shown by the heavy dotted arrows in Figure 43-41). C_2 has a shorter charging time constant, due to the lower RC product of its charging path (shown by the heavy solid arrows). Capacitor C_1 has a short discharge time constant, its discharge path being shown by the light dotted arrows. C_2 has a long discharge time constant, its discharge path being shown by the light solid arrows in Figure 43-41.

The waveforms used in the analysis of the circuit are shown in Figure 43-42. These waveforms were obtained by connecting OS-8C/U into the sweep generator circuit of a second OS-8C/U oscilloscope. The vernier frequency control of the test OS-8C/U oscilloscope was set fully clockwise and the coarse frequency set in the number three (100-475 cps) position.

Analysis of the circuit is begun at T_1 (Figure 43-42), at which time an inspection of the waveforms indicates the oscillator has just completed its retrace and is starting the sweep portion of its cycle. This is evident from the fact that e_{b1} (which is also the voltage across the saw forming capacitor) is at its minimum value. At this instant V_2 is conducting, and its current is causing approximately 0.7 of a volt to be dropped across the cathode resistor R_1. V_2's plate voltage is near its minimum value, causing C_2 to discharge through grid resistor R_2. This applies a large negative potential to the grid of V_1, as shown by the e_{R2} waveform at T_1. Since V_1 is cut off at this time, the saw tooth capacitor (C_1) will begin charging towards B+. However, its charging time constant is such that it will only reach a value of approximately 70 volts by T_2. Thus, only 20% of C_1's charge curve is used, providing a relatively linear sweep.

As C_2 discharges between time one (T_1) and time two (T_2), the grid voltage of V_1 (e_{R2}) decreases towards V_1's cut-off value (approximately -12 volts). Also notice that between T_1 and T_2, V_2's plate current increases slightly (as indicated by the gradual decrease of plate voltage waveform e_{b2}). This is caused by the fact that a portion of V_2's bias, during this time, is derived from the discharge of C_2 through R_1. As C_2 discharges, the bias on V_2 decreases, causing a gradual increase in plate current.

At T2 e_{R2} reaches -12 volts and V_1 begins to conduct. At this instant an action similar to the switching action of a normal multivibrator takes place, and V_2 is cut off, V_1's plate current increases the cathode bias on V_2). The rounding of e_{b2}'s leading edge is caused by the action of C_2's charging current through R_5. The charging current of C_2 causes a positive potential on the grid of V_1, which increases its plate current and lowers its plate voltage. The lowering of V_1's plate voltage causes C_1 to discharge rapidly through the relatively low resistance of R_1 and the plate resistance of V_1 (as indicated by the retrace portion of the sawtooth waveform e_{b1}). At the instant T_2, the current through R_1 consists of V_1's plate current, V_2's plate current, the charging current of C_2, and the discharge current of C_1. As expected, these currents will cause a sharp rise in the voltage

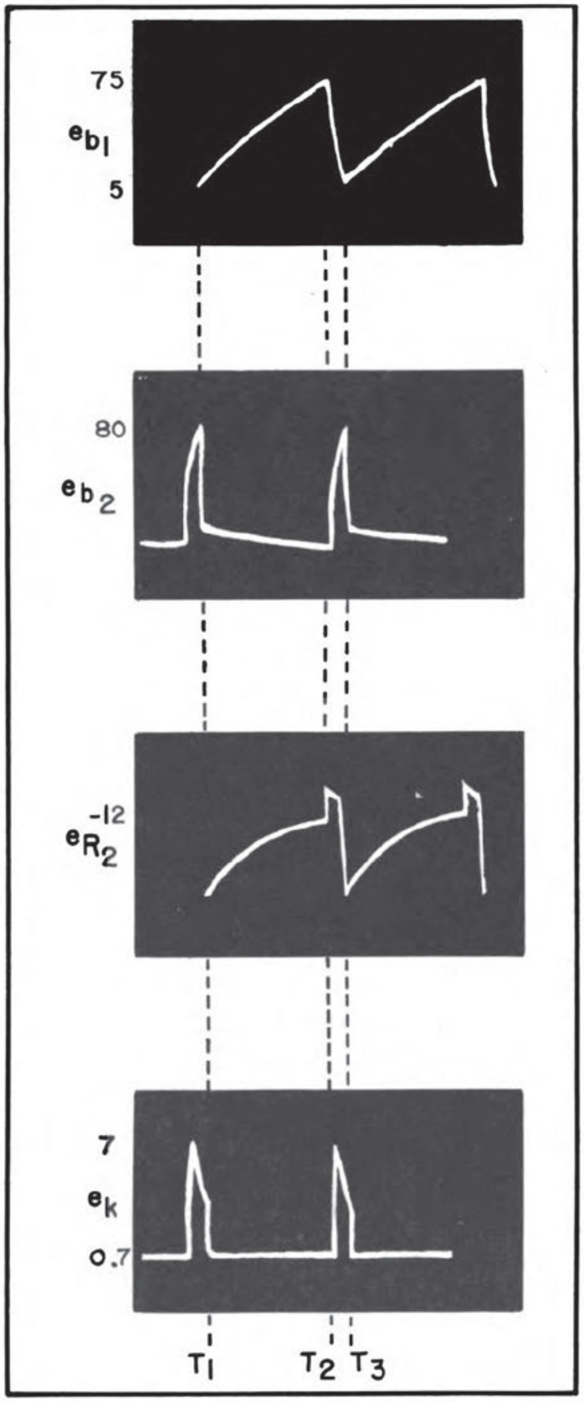

Figure 43-42 - Waveforms.

across the cathode resistor R_1 (notice the sharp increase in waveform e_k, Figure 43-42). The cathode voltage, at T_2, is approximately 7 volts. This effectively applies a -7 volts bias to V_2. As C_2 charges, the positive grid voltage decreases (e_{R2} decreases between T_2 and T_3). As C_1 discharges, its current through R_1 decreases (exponential decrease of e_k between T_2 and T_3). As the cathode voltage decreases, V_2's plate voltage will decrease, until (at T_3) V_2's plate voltage falls below the potential on the positive plate of C_2. This will cause C_2 to begin discharging and initiate the cut-off of V_1 and the charge of C_1.

At this point the circuit has completed a cycle of operation. Time one (T_1) to time two (T_2) represents the sweep portion of the oscillator's cycle and time two to time three (T_3) represents the retrace portion of the oscillators cycle.

The actual schematic of the OS-8C/U oscilloscope sweep generator is shown in Figure 43-43. A six position switch (S_{104}, coarse frequency) provides an operating range from 3 cps to 50 kc. This range of frequencies is controlled by utilizing capacitors C_{125} through C_{131}. These capacitors act alternately and respectively as sawtooth generating capacitors for the second triode section (V_{108B}), and as coupling capacitors between the first and second triode sections. For example: With the coarse frequency switch S_{104} set in position six (as shown in Figure 43-43), capacitor C_{130} is connected between the plate of V_{108B} and ground, where it functions as a sawtooth capacitor. C_{131} functions as the coupling capacitor in position six. However, when S_{104} is turned to position five, C_{130} (which was the sawtooth capacitor) now becomes coupling capacitor, and C_{129} becomes the sawtooth capacitor.

Adjusting the operating frequency within a given range (as determined by the coarse frequency switch) is accomplished by use of the vernier frequency control. Examination of Figure 43-43 shows that the vernier frequency control consists of a 5 megohm and a 1 megohm potentiometer "ganged" on the same shaft. The 5 megohm potentiometer effects the operating frequency by varying the plate voltage of V_{108B}, and the 1 megohm potentiometer effects the operating frequency by varying the RC product of the coupling network. The sawtooth output of the V_{108B} section is applied to an ac voltage divider, consisting of R_{155} and R_{125}. Since the ratio of these resistances is approximately 10 to 1, the sawtooth waveform developed across R_{125} (and fed to the horizontal cathode follower as the output of the sweep generator) will be one tenth the amplitude of the V_{108B} sawtooth. Capacitors C_{142}, C_{123}, and C_{113} are frequency compensating components while C_{124} functions as a coupling and dc isolation capacitor. R159 is a grid current limiting resistor. The effect of this resistor is to provide a sharper output pulse.

Q31. What is the purpose of the capacitor between the plate of V_{108B} and ground?

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A31. To charge up slowly during the time V_{108B} is cut off thus forming a saw-tooth waveform.

Q32. If S_{104} was moved from position 1 to position 2, what would happen to the cut-off time of V_{108B}?

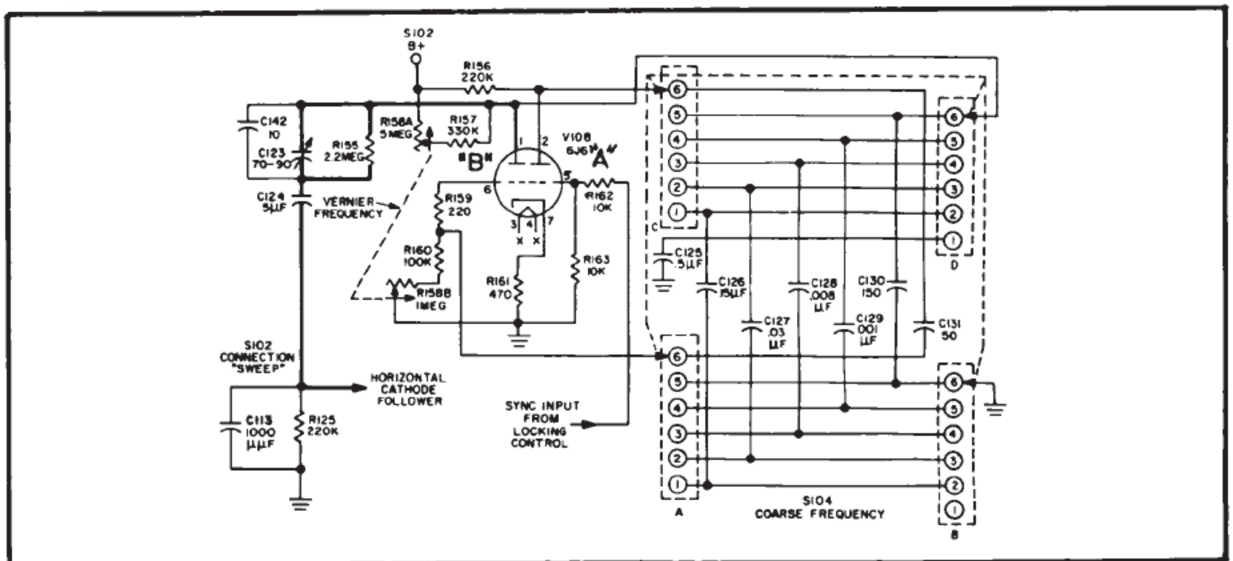

Figure 43-43 - OS-8C/U Sweep oscillator.

43-11. Sync Selector and Amplifier

Free running **multivibrators** are not frequency stable and must be synchronized. Synchronization must also be provided in the OS-8C/U. A synchronization channel is provided

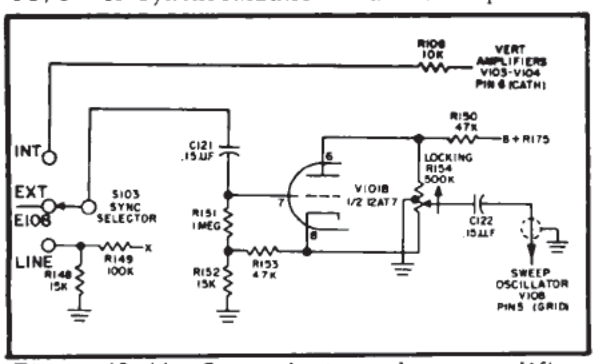

Figure 43-44 - Sync selector and sync amplifier.

to synchronize the sweep circuit oscillator. The two blocks used to supply a synchronizing signal to the sweep oscillator in the OS-8 are the sync selector and the sync amplifier as shown in the detailed block diagram of the OS-8C/U.

Referring to Figure 43-44 the sync selector switch, S_{103}, provides a means of selection either external, internal or line frequency voltages to permit synchronization of the sweep oscillator. Line frequency voltage is supplied from one-half of the "X" filament winding of the power transformer and is 60 cps. External synchronization voltages are applied to the EXT. SYNC. binding post, E_{108}, from an outside source when the internal sources are not of sufficient amplitude etc. The internal frequency is supplied from the unbypassed cathode of the push-pull power stage of the vertical deflection amplifier, and through the decoupling resistor R_{108}. It should be remembered, it is desired that the start of the sawtooth and the vertical signal be synchronized.

The output from the sync selector switch S_{103} is coupled by C_{121} to the grid of V_{101B} (sync amplifier) with R_{151} as the grid resistor. R_{153} acts as the cathode biasing resistor. Plate voltage is obtained from the voltage divider network composed of 1/2 of R_{154} in series with the plate load resistor R_{150}. This circuit is supplied by the low voltage B+ supply. The LOCKING control R_{154} is connected from plate to cathode of V_{101B} and has a fixed center tap which is connected to ground.

An analysis of the circuits between the plate of V_{101B} and ground will show that with a signal applied to the control grid, the high end of the LOCKING control, R_{154}, will be electrically receiving signals developed at the plate of this tube; and the low end of the LOCKING control will be receiving signals from the cathode. When this control is at approximately the center of its rotation there is no signal since the center of the control is grounded. If this control is operated toward the plate side of R_{154} a locking voltage would be obtained which would be out of

phase with the signal applied to the grid. If the LOCKING control is advanced toward the cathode side of R_{154} the locking voltage applied to the sweep circuit oscillator would be in phase with the synchronizing signal on the control grid.

As a result of this circuit, the sweep circuit oscillator may be locked in with respect to incoming synchronizing signals, either in phase or out of phase with these voltages. The amplitude of the output signal increases as the arm on R_{154} is moved away from the center position, thus providing a method of selecting the amplitude of the output as well as the polarity.

From the variable arm of R_{154} the sync signal is coupled to the sweep oscillator at pin 5 of V_{108} through the coupling capacitor C_{122}.

Q33. If the sync selector was in the internal position where would the sync signal be coming from?

Q34. How many possible outputs can be obtained from the sync amplifier?

Q35. If the sync selector were in the external position and positive triggers were being fed into E_{108}, what polarity triggers would be fed to pin 5 (control grid) of V_{108A} if the arm on the locking control was at the bottom of R_{154}?

43-12. Intensity Modulation

During the time that the sawtooth capacitor is discharging and the multivibrator coupling capacitor is charging, (conduction time of V_{108B}), the cathode voltage increases. This develops a positive pulse at the cathode (Figure 43-42) during the retrace time of the sawtooth waveform. This pulse has exactly the same time duration as the retrace time of the sawtooth capacitor, and is positive in polarity. This pulse may be applied through the jumpered contacts on the terminal board on the rear of the oscilloscope, to the grid of the INTENSITY MODULATION amplifier, V_{105B} (Figure 43-45).

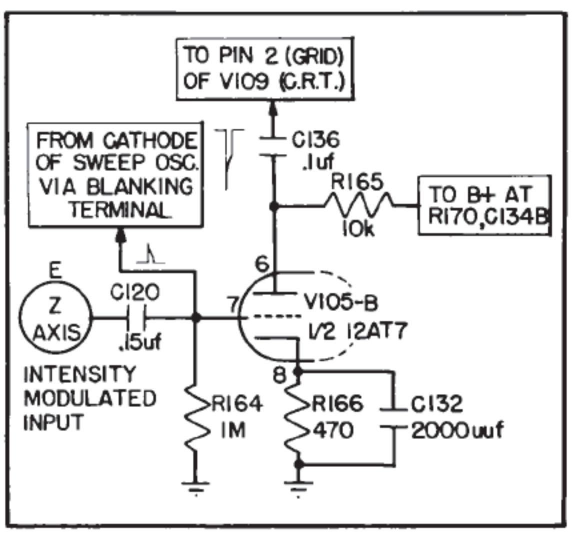

Figure 43-45 - Intensity modulation amplifier.

The intensity modulation amplifier will amplify and invert the signal. Then the signal will be coupled through C_{136} to the control grid of the cathode ray tube as a high negative signal to blank out the beam during retrace. This action is known as BLANKING. Figure 43-46 shows the effect of blanking as compared to no blanking on an oscilloscope screen. If the blanking pulses were of large enough amplitude (perhaps 25 to 50 volts in some cases), the blanking pulses could be applied directly to the CRT. They could be applied to the grid if they were negative, and to the cathode if they were positive. However, the blanking pulse is so small that it must be amplified. This is the function of the intensity modulation amplifier.

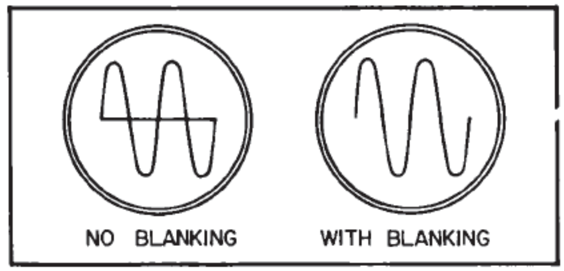

Figure 43-46 - Effects of retrace blanking.

Occasionally it is necessary to produce a series of evenly spaced markers along a trace, when internal blanking is disconnected. These markers provide a scale for measurement of equal periods of time. The markers can be either positive pulses, which will brighten the trace, or they may be negative pulses, which will blank out part of the trace when applied to

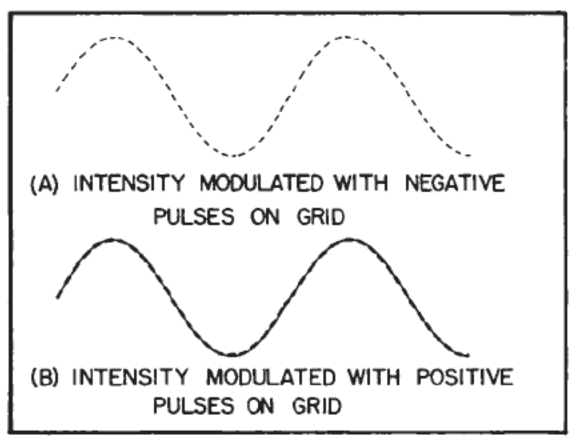

Figure 43-47 - Intensity modulation.

A32. It would decrease.

A33. The vertical amplifiers.

A34. Two.

A35. Positive.

the control grid of the CRT. Figure 43-47A illustrates the use of markers which will blank out part of the trace, while Figure 43-47B illustrates markers which intensify the trace. The external marker source is connected to the Z axis binding post of the scope, and is RC coupled to the intensity modulation amplifier which amplifies and inverts the signal (Figure 43-45). The signal is now applied to the CRT. In the OS-8C/U the pulses are RC coupled to the control grid of the CRT.

EXERCISE 43

1. What are the requirements of the sawtooth waveform which is produced by the sweep circuits in an oscilloscope?
2. What is a sawtooth waveform used for in an oscilloscope?
3. If four cycles of a 100 Kc sine wave were seen on a scope, what would the frequency of the sawtooth generator be?
4. Why is it necessary to synchronize the sawtooth generator?
5. What blocks in the detailed block diagram of the OS-8C form the sweep circuits?
6. What circuit condition in the neon tube sawtooth generator produces the rise time of the waveform?
7. If the size of the capacitor in the neon tube sawtooth generator increased, what would happen to the output waveform, amplitude, frequency, linearity and duration?
8. What is normally called the coarse frequency in a sawtooth generator?
9. What happens to the output duration, amplitude, frequency and linearity if the B+ applied to a gas tube sawtooth generator is increased?
10. Why is the B+ in a gas tube sawtooth generator normally set quite high with respect to the ionizing point of the tube?
11. If bias is increased in a thyratron sawtooth generator what happens to: the firing potential, output amplitude, output duration, output frequency and output linearity?
12. How does a variation in bias in a thyratron affect the deionizing point?
13. When synchronizing a thyratron sawtooth generator with a sine wave, how would the natural frequency of the circuit be adjusted with respect to the desired output frequency?
14. Is there any limit to the amplitude of the sine wave sync voltage that can be used with a thyratron sawtooth generator?
15. What would happen to the output frequency of a thyratron sawtooth generator if a multiple frequency sync signal was being used and its amplitude were made very large?
16. What determines the output frequency of the hard tube sawtooth generator?
17. What is the polarity of the gate pulse used to trigger the hard tube sawtooth generator?
18. What effect on output amplitude does an increase in the duration of the trigger to a hard tube sawtooth generator have?
19. If in question 18, the amplitude is required to be maintained at a constant level, what could have been done to R or C?
20. What effect on the output frequency of a hard tube sawtooth generator would an increase in R or C cause?
21. What type of an output do multivibrators produce?
22. What three basic types of multivibrators are there?
23. How many stable conditions does the Eccles-Jordan multivibrator have?
24. If the trigger input frequency of a multivibrator is 8 Kc, what is the output frequency?
25. If the input triggers to an Eccles-Jordan multivibrator are positive, which tube would be affected by them?
26. What is the relationship of the plate voltage waveforms in a multivibrator?
27. Where is the output from an Eccles-Jordan multivibrator taken?
28. Which tube in the one-shot cathode coupled multivibrator is normally conducting?
29. What must be the polarity of the triggers used by a monostable multivibrator?
30. What determines the length of time V_1 conducts in the one-shot multivibrator after being triggered?
31. How many input triggers are required by the one-shot multivibrator for one cycle of the output waveform?
32. What is the reason for returning the grid resistor to B+ in the one-shot multivibrator?
33. Must the Eccles-Jordan and the one-shot multivibrators be triggered?
34. What type of multivibrator is the basic plate coupled multivibrator?
35. What determines the length of time V_2 is cut off in the free running plate coupled multivibrator.
36. If the size of C_1 in the free running plate coupled multivibrator were increased, what would happen to the conduction time of V_2, the cut-off time of V_1, and the frequency?
37. What causes the rounded leading edge of the plate waveforms of the free running plate coupled multivibrator?
38. If the cut-off time of V_1 in a symmetrical multivibrator is 500 u sec, what is the frequency?
39. If the size of the plate load resistor for V_1 in a free running plate coupled multivibrator were increased, what would happen to: the amplitude of e_{p1}, the cut-off time of V_2, and the frequency?
40. In order to synchronize a multivibrator which of the following should be greater its synchronizing frequency or its free run frequency?
41. How do positive sync triggers applied to the grid of a free running plate coupled

EXERCISE 43

multivibrator synchronize the circuit?

42. What determines the length of time V_1 is cut off in the free running cathode coupled multivibrator with capacitor coupling between the cathodes?
43. What determines the cut off time of V_2 in the free running cathode coupled multivibrator with capacitor coupling?
44. The plate waveform of V_2 in a free running cathode coupled multivibrator is more rectangular than the plate waveform of V_2 in the plate coupled multivibrator. Why?
45. What resistor in the free running cathode coupled multivibrator is normally used to control the output frequency?
46. Which tube is cut off for the longest period of time in the free running cathode coupled multivibrator with direct coupled cathodes?
47. What determines the conduction time of V_1 in the free running cathode coupled multivibrator with direct coupled cathodes?
48. What type of multivibrator is used for the sweep oscillator in the OS-8C/U?
49. What is added to the basic multivibrator circuit used in the sweep oscillator in the OS-8C/U so that a sawtooth waveform can be produced?
50. What basically determines the frequency of the sweep oscillator in the OS-8C/U?
51. What component in the sweep oscillator of the OS-8C/U insures that sweep amplitude doesn't change when frequency changes?
52. The positive pulse on the cathode of the sweep oscillator occurs when which section of the tube is conducting? Why?
53. What is the purpose of the sync selector?
54. What signal, source, internal, external or line is normally the best one to use as a synchronizing signal for the sweep oscillator?
55. Where does the blanking pulse originate?
56. What is the purpose of blanking?
57. How is intensity modulation used in an oscilloscope?

CHAPTER 44

VERTICAL AND HORIZONTAL AMPLIFIERS

The oscilloscope is a test instrument which must display an exact duplicate waveform of the signal or signals applied to its input. This means the oscilloscope must not cause any distortion of the applied signals. This is accomplished through the use of linear class "A" amplifiers. The oscilloscope also must have a high input impedance to reduce the loading effect on the circuit or equipment being tested.

The function of the horizontal and vertical amplifiers, in the oscilloscope, is to amplify the signal applied to them with minimum distortion. These amplified signals are then applied to the horizontal and vertical deflection plates in the CRT, which will cause horizontal and vertical deflection of the electron beam.

The horizontal amplifier section of a typical Navy oscilloscope will now be analyzed.

44-1. Horizontal Amplifiers

The horizontal amplifier channel is shown in block diagram form in Figure 44-1. It consists of the horizontal attenuator, horizontal cathode follower, the first and second direct coupled amplifiers and the cathode ray tube. During the following discussion, reference to this block diagram will aid in your understanding of the basic operation of the following circuits.

There are three possible inputs to the horizontal channel. Two external inputs and one internal. In the majority of cases when using an oscilloscope a linear time base is desired. In this case the signal fed into the horizontal channel would come from a sweep generator located inside the oscilloscope. In special cases a signal other than a sawtooth is used for horizontal deflection and the external inputs would be used. The selection of these various inputs is made with the horizontal attenuator switch. All inputs to the channel, except the external dc input, are fed to the horizontal cathode follower stage. The purpose of the horizontal amplifier is to increase the strength of the horizontal signal to achieve adequate lateral (horizontal) deflection of the CRT beam.

44-2. Horizontal Attenuator

The purpose of the horizontal attenuator is to select the desired type and adjust the strength of the signal fed into the horizontal channel.

Since the input signal can vary considerably in amplitude, a means of coarse as well as fine amplitude adjustment is desirable. This is usually accomplished by the use of a step-switch attenuator and potentiometer.

44-3. Basic Step-Switch Attenuator

A basic step-switch attenuator is shown in Figure 44-2.

The tapped resistor is merely an ac voltage divider where the output voltage (input to the HORIZONTAL amplifier) depends on the position of switch S_1. The taps occur at calibrated intervals so the amount of attenuation or reduction of the input is known by the switch position. As the frequency applied to this network increases, the stray and input capacitance (represented by C_s) causes a shunting effect across the tapped portion of the voltage divider. This shunting action changes the resistance and impedance

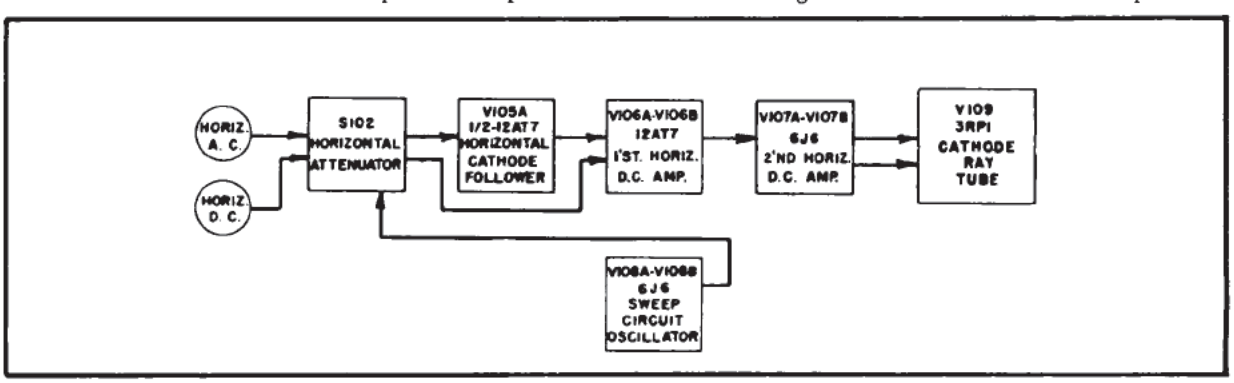

Figure 44-1 - Block diagram of horizontal channel.

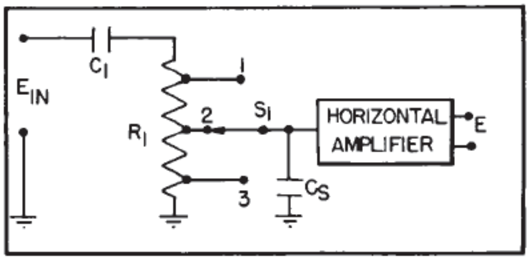

Figure 44-2 - Basic step-switch attenuator.

ratios originally used in calibration. For this reason most attenuators have a high frequency compensating network added.

44-4. Practical Attenuator

A typical step attenuator with high frequency compensation is shown in Figure 44-3. With switch S102 in the AC-1 position, R128 is shorted out, and the input is not attenuated, but is fed directly into the horizontal cathode follower stage. This position would be used for very weak signals where maximum deflection sensitivity is needed.

When switch S102 is in the AC-10 position, the input is reduced by a factor of 10 and in the AC-100 position it is reduced by a factor of 100. This means that in the AC-10 position 1/10 of the input is fed to the next stage and in the AC-100 position, 1/100 of the input is used.

With the horizontal attenuation control in the dc position, the connection to the horizontal ac input is removed, and the horizontal dc input jack E105 is connected to the horizontal gain control which can be used to adjust the magnitude of the dc voltage input before it is applied to the first horizontal dc amplifier thus bypassing the horizontal cathode follower. A simplified circuit illustrating the switch in the AC-10 position is shown in Figure 44-4.

For all frequencies applied to the attenuator the resistors R128 and R126 have a ten to one resistance ratio. This resistance ratio would be adequate if the stray and input capacities of the next stage were not present. These capacities, represented by C_S, tend to have greater shunting effect on R126 as the input frequency is raised. To compensate for this shunting effect C111 and C114 are added to the network. Their values are chosen to give an approximate reactance ratio between C111 and the combined parallel capacity of C114 and C_S of ten to one. This is calculated at the highest frequency to be passed. In the circuit shown in Figure 44-3 the upper frequency limit is 500 kc. Because of the difficulty of calculating the stray and input capacitance, and since it might vary for different tubes and operating voltages, C111 is made variable to achieve this ratio under operating conditions.

When switch S102 in Figure 44-3 is in the sweep position, the sweep generator is started and its output is fed to the input of the cathode follower stage. The length of the trace which this sawtooth voltage eventually produces can be varied by the horizontal gain control.

To prevent the shunting of the step attenuator, the stage following it should have a high input

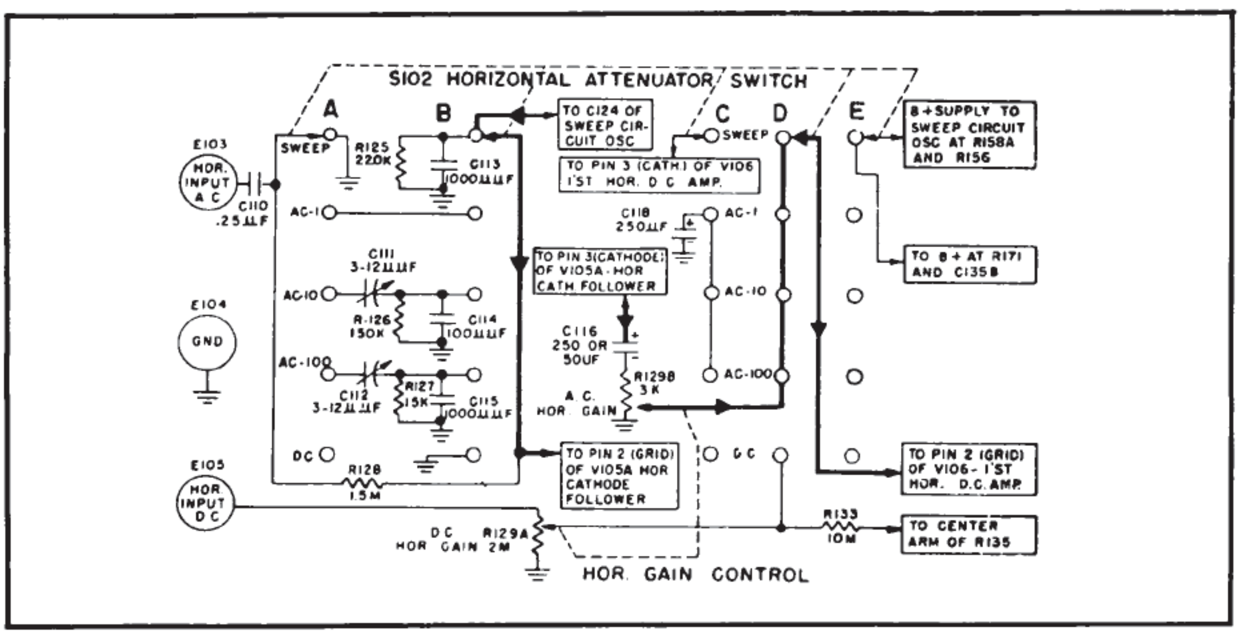

Figure 44-3 - Horizontal input attenuator.

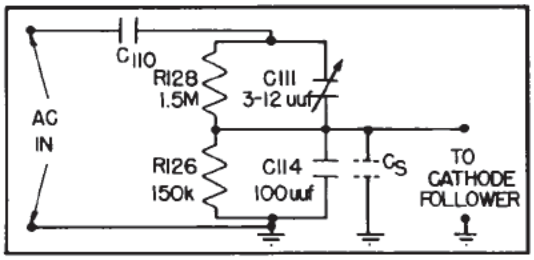

Figure 44-4 - Simplified attenuator.

impedance and low input capacity. A circuit which has these characteristics is a cathode follower and will be discussed next.

Q1. What is the purpose of the horizontal attenuator?

Q2. What does the horizontal switch S102 do to the sweep generator in the sweep position?

Q3. What controls the amount of horizontal deflection when the horizontal attenuator is in the sweep position?

44-5. Horizontal Cathode Follower

The basic cathode follower is a single stage, class A, degenerative amplifier, the output of which appears across the unbypassed cathode resistor. No plate load resistor is used and the plate is at ac ground. The basic cathode follower circuit is shown in Figure 44-5.

When the positive alternation of the input signal is applied to the grid, plate current increases. The increase in plate current will cause a greater voltage drop across the cathode resistor. Since the plate current will vary sinusoidally, the voltage drop across the cathode resistor, E_{Rk}, will also vary sinusoidally as shown in Figure 44-5. The output will be a sine wave, the reference level of which is the quiescent cathode voltage.

Equating a series loop from the grid to the cathode the ac voltage changes are series

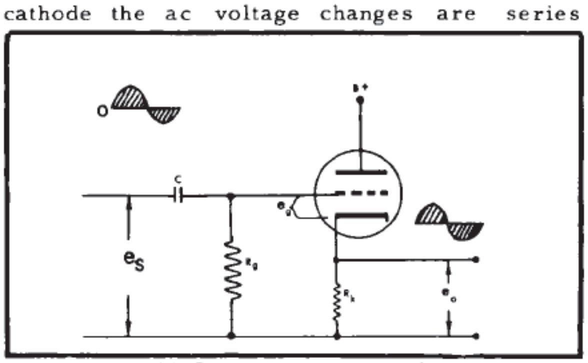

Figure 44-5 - Basic cathode follower.

opposing. In Figure 44-5 the following is therefore true:

$$e_g = e_s - e_o \qquad (44\text{-}1)$$

where: e_g = ac grid to cathode voltage
e_s = ac input signal
e_o = ac output signal

The tube plate current is controlled by e_g. If the output voltage change, e_o, were to equal the input voltage change, e_s, the grid voltage, e_g, change would be zero resulting in no original change in plate current. This is an impossible condition. Therefore, the ac output voltage from a cathode follower must always be less than the input voltage. For this reason, the voltage gain of a cathode follower is less than unity although it will subsequently be shown that the circuit is capable of a power gain. As the name implies, the output voltage follows the input voltage. It not only has the same waveform, but also the same instantaneous polarity. It should be noted that the voltage gain of less than unity only applies to the ac voltages and not to the dc component of the output.

The circuit shown in Figure 44-5 can be represented by the equivalent circuit shown in Figure 44-6.

where: μ = amplification factor
r_p = ac plate resistance
e_g = as shown in formula 44-1

According to Ohm's law:

$$i_p = \frac{\text{voltage applied}}{\text{total resistance}}$$

then:
$$i_p = \frac{\mu e_g}{r_p + R_k} = \frac{\mu(e_s - e_o)}{r_p + R_k} \qquad (44\text{-}2)$$

since: $e_o = e_{Rk} = I_p R_k$

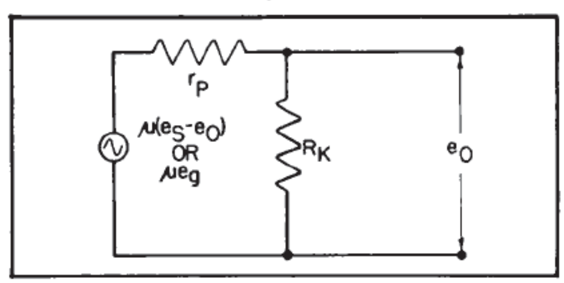

Figure 44-6 - Equivalent circuit of a cathode follower.

A1. To adjust the amplitude of the signal fed to the horizontal amplifier.

A2. Section E of the switch applies B+ to the sweep generator and section B of the switch couples the sweep generators output into the horizontal cathode follower.

A3. The ac horizontal gain control.

---

substituting in equation (44-2) gives:

$$i_p = \frac{\mu(e_s - i_p R_k)}{r_p + R_k}$$

This equation can be solved for i_p as follows:

$$i_p(r_p + R_k) = \mu e_s - \mu i_p R_k$$

$$i_p(r_p + R_k) + \mu\, i_p R_k = \mu\, e_s$$

$$i_p(r_p + R_k + \mu\, R_k) = \mu\, e_s$$

$$i_p = \frac{\mu\, e_s}{r_p + R_k + \mu\, R_k}$$

$$i_p = \frac{\mu\, e_s}{r_p + R_k(\mu + 1)}$$

since: $$e_o = i_p R_k$$

$$e_o = \frac{\mu e_s R_k}{r_p + R_k(\mu + 1)}$$

The voltage gain of the amplifier is equal to:

$$\text{voltage gain} = \frac{e_o \text{ (voltage out)}}{e_s \text{ (voltage in)}}$$

therefore:

$$\text{voltage gain} = \frac{e_o}{e_s} = \frac{\mu\, e_s R_k}{r_p + R_k(\mu + 1)} \div e_s$$

$$\text{voltage gain} = \frac{\mu\, e_s R_k}{r_p + R_k(\mu + 1)} \times \frac{1}{e_s}$$

$$\text{voltage gain} = \frac{\mu\, R_k}{r_p + R_k(u + 1)} \qquad (44\text{-}3)$$

Upon examination of equation (44-3) it can be seen that the denominator will always be greater than the numerator thus the voltage gain of the cathode follower will always be less than one.

In comparing the output voltage formula of a cathode follower to a conventional triode RC coupled amplifier, the tube used as a cathode follower appears to have an amplification factor equal to $\mu/\mu + 1$, and an ac plate resistance equal to $r_p/\mu + 1$. From this comparison another equivalent circuit may be drawn that more closely represents the cathode follower. This modified equivalent circuit is illustrated in Figure 44-7.

Q4. What is the phase relationship between the input signal and the output signal of a cathode follower?

Q5. How does the amplification factor of a tube used as a cathode follower compare to the amplification factor of a conventional RC coupled amplifier?

44-6. Output Impedance

The impedance (Z_o) "looking back" from points A and B in Figure 44-7 consists of a parallel network composed of the ac plate resistance $\frac{r_p}{\mu + 1}$ and the cathode resistor. The constant voltage generator may be considered a short circuit. Therefore, the following equation may be used to determine the value of the output impedance, Z_o.

Using the product over the sum formula for parallel impedance:

$$Z_o = \frac{\frac{r_p}{1 + \mu} \times R_k}{\frac{r_p}{1 + \mu} + R_k}$$

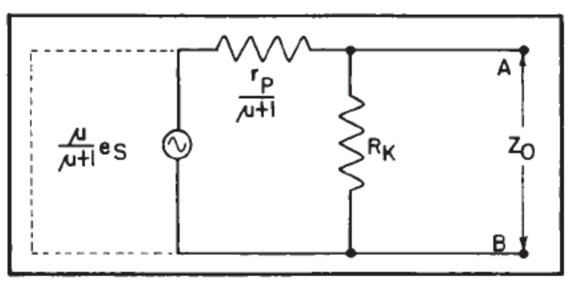

Figure 44-7 - Modified equivalent circuit of cathode follower.

$$Z_o = \frac{r_p R_k}{r_p + (1 + \mu) R_k} \qquad (44\text{-}4)$$

In general, this equation shows that the output impedance (Z_o) of a cathode follower is less than R_k and is usually resistive in nature. This makes the cathode follower capable of feeding a low impedance load.

44-7. Input Impedance

The input impedance of a cathode follower is high and the effective input capacitance is low when compared with like values of a conventional amplifier.

Both of these characteristics of the cathode follower result from the degenerative action that occurs due to the un-bypassed cathode resistor. The equivalent circuit for the input impedance is shown in Figure 44-8.

The apparent input impedance as seen by the generator is Z_a. The input signal is represented by e_s. According to Ohm's law:

$$I_s = \frac{e_s}{Z_a}$$

Since the output voltage opposes the input voltage, the voltage applied between the control grid and cathode equals $e_s - e_o$.

According to Ohm's law:

$$I_g = \frac{e_s - e_o}{Z_g} \text{ or } \frac{e_g}{Z_g}$$

Since the current in these two equations is the same:

$$\frac{e_s}{Z_a} = \frac{e_g}{Z_g}$$

and:

$$Z_a e_g = e_s Z_g$$

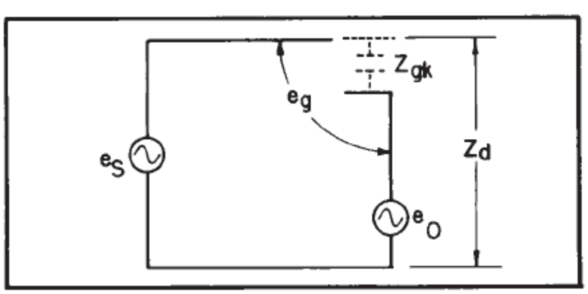

Figure 44-8 - Input impedance.

therefore: $$Z_a = \frac{e_s Z_g}{e_g}$$

Dividing through by e_s:

$$Z_a = \frac{Z_g}{\frac{e_g}{e_s}}$$

Substituting equation (44-1) for e_g:

$$Z_a = \frac{Z_g}{\frac{e_s - e_o}{e_s}}$$

$$Z_a = \frac{Z_g}{1 - \frac{e_o}{e_s}}$$

$$\frac{e_o}{e_s} = \text{voltage gain } A$$

therefore: $$Z_a = \frac{Z_g}{1 - A} \qquad (44\text{-}5)$$

In the equation (44-5) the denominator will always be less than one so the apparent input impedance Z_a, as seen by a source, will always be larger than the input impedance of a conventional amplifier.

The reduced input capacitance results from the fact that degeneration reduces the amplitude of the ac component of the grid-to-cathode voltage, or in effect increases the input impedance, and thus causes less current to flow through the tube capacitances.

Q6. Why is the ouptut impedance of a cathode follower less than the value of R_k?

Q7. What effect does the low input capacity of a cathode follower have on the previous stage?

44-8. Advantages of Cathode Followers

One of the principal advantages of a cathode follower is that it can be used to match a high impedance to a low impedance. Thus it can take the voltage developed across a high impedance and supply a low impedance load with only a slightly less voltage but with a correspondingly large increase in current. One or more of the circuit elements of a cathode follower may be varied to achieve a more precise impedance match if the match is critical.

A4. They are in phase. e_g and i_b are in phase and e_o is caused by i_b through R_k.

A5. The conventional amplifier has an amplification factor of u and a cathode follower has an apparent amplification factor of $\frac{\mu}{\mu+1}$.

A6. The apparent ac plate resistance appears in parallel with R_k and lowers the total impedance.

A7. The lower the input capacity, the less the shunting effect at high frequencies. The result is a better high frequency response.

When tubes having a high mutual conductance are used, the low value of output impedance extends the amplification into the upper range of frequencies because the shunting effects of interelectrode and distributed capacitances are proportionately smaller. The low-frequency response is improved by allowing the dc component of cathode current to flow in the load, thus avoiding the use of a series blocking capacitor.

The degenerative effect caused by the unbypassed cathode resistor increases the input impedance. Thus less shunting effect is offered to the previous stage, and a better overall frequency response is produced.

As stated before, the input and output voltages have the same instantaneous polarity. When pulses are used it may be necessary to feed a positive- or a negative-going pulse to a load without polarity inversion. The cathode follower could thus serve two purposes: to prevent polarity inversion and to afford an impedance match.

Circuit stability is also improved, as in regular amplifiers, by degenerative feedback. Specifically, amplitude distortion occurring within the tube, the effect of plate supply voltage variations, aging of tubes, production of harmonics, and other undesirable effects that occur within the stage are counteracted by this type of circuit.

However, these advantages are achieved at the expense of an overall reduction in voltage gain. Normally, the voltage gain is slightly less than unity, but the circuit is capable of producing a gain in power.

Q8. What is the phase relationship between the input and output voltage of a cathode follower?

44-9. Practical Cathode Follower

Due to its high input impedance and low output impedance, the cathode follower can be used to match the impedance of a step-attenuator to a variable gain control. A typical cathode follower used in the horizontal channel of an oscilloscope is shown in Figure 44-9. It should be noted that the heavy black line represents signal flow and not necessarily current flow.

Any voltage applied to the control grid pin 2 will appear slightly reduced across the cathode resistor R_{132}. This signal is capacitively coupled to the horizontal ac gain control. Blocking capacitor C116 blocks the dc component of the output and passes only the ac signal. Due to the impedance characteristics of the cathode follower, the gain control (possessing a small value of resistance, 3k), has a negligible loading effect on the input. The gain control provides fine adjustment of the signal fed into the first horizontal dc amplifier. It must be remembered that the step switch attenuator and the horizontal gain control together set the amplitude of the ac signal fed into the first horizontal amplifier.

Under normal operating conditions the output of a cathode follower stage is practically free of amplitude distortion. However, if the input signal swings the grid voltage too far negative, the output waveform will be limited or distorted in amplitude with respect to the input waveform. Beyond a certain negative value of grid voltage the plate current will be cut off and any further increase in negative grid potential will cause no corresponding change in plate current.

To prevent this distortion the attenuator should be at the maximum attenuation position before applying a signal of unknown amplitude to the horizontal channel.

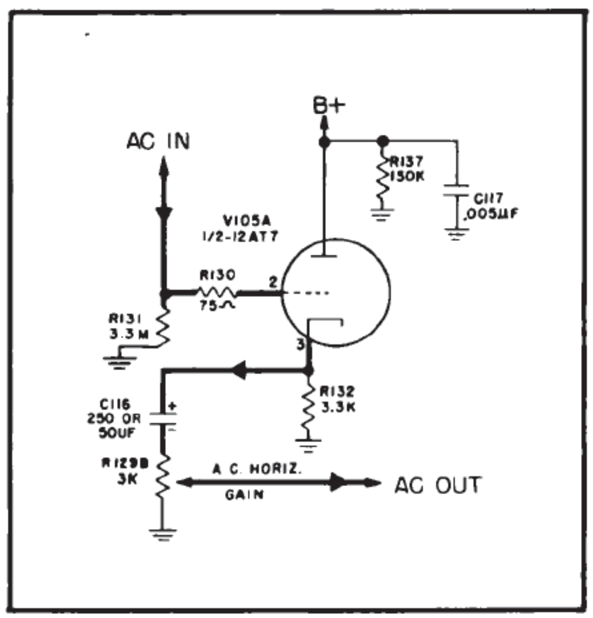

Figure 44-9 - Horizontal cathode follower.

In the practical cathode follower circuit in Figure 44-9, the input resistor is in parallel with the apparent input impedance discussed in section 44-8. The actual input impedance can be no higher than the value of this grid resistor, but the loading effect on this resistor is much less in a cathode follower stage than in a conventional amplifier. R_{137} acts as a bleeder resistor for C_{134C}.

The horizontal cathode follower feeds the first direct coupled amplifier.

Q9. What causes distortion of the output signal of a cathode follower?

Q10. In a practical cathode follower what effect does the grid leak resistor have on the input impedance?

DIRECT COUPLED AMPLIFIERS

44-10. Basic Direct Coupled Amplifier

An amplifier whose coupling networks consists of direct connections is called a dc (DIRECT COUPLED) amplifier. A direct coupled amplifier is used to amplify direct current voltage changes as well as ac voltage changes. The use of direct coupled amplifiers in the horizontal channel of an oscilloscope permits an ac signal voltage to be superimposed on a dc reference voltage, thus providing a method of centering or positioning the pattern on the face of the CRT. This method of centering will be discussed later.

The simplest form of dc amplifier consists of a single tube with a grid resistor across the input and a load connected in the plate circuit, as shown in Figure 44-10A.

The direct current voltage change to be amplified is applied directly to the grid of the amplifier tube. Therefore, direct coupling is required in the input circuit. A capacitive input circuit is also shown to indicate how the capacitor changes the direct current voltage to an ac signal.

In the capacitor input circuit of Figure 44-10B, graphs of the signal voltage, grid voltage and plate current are shown.

The applied dc voltage charges the capacitor and momentarily the voltage drop across R_g equals the applied voltage change. This voltage then appears between the grid and cathode of the tube. However, when the capacitor is charged up to the value of the dc input voltage, the current stops flowing through R_g and the grid returns to its original value, that of the bias voltage. Thus, except for the original surge of plate current, which occurs when the capacitor is charging, there is no increase in voltage across R_L and hence no amplification.

In the direct coupled input circuit of Figure 44-10A, the graphs of input signal, grid voltage, and plate current are shown above the circuit. The input signal is like that in Figure 44-10B but here the similarity ends. With no input signal the negative bias voltage is present on the grid of the tube and a steady value of plate current flows. This action causes a fixed voltage drop across R_L. When a direct voltage of the polarity indicated is applied across the input terminals, there is no blocking action by a capacitor as in the previous case. Instead, the applied signal continues as a steady voltage drop across R_g canceling a portion of the negative bias. The net bias then drops to the new value indicated in the grid voltage graph. This reduction in grid bias causes a greater current flow in the plate circuit, and thus a

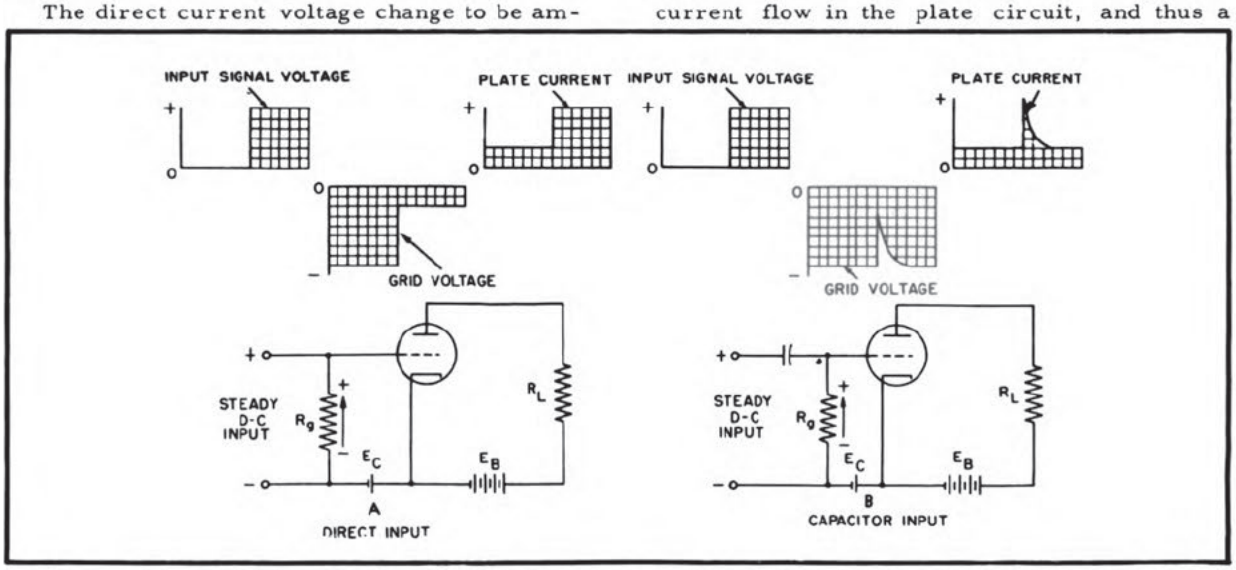

Figure 44-10 - Comparison of direct input and capacitor input to dc amplifier.

A8. The input and output voltage are in phase and have the same instantaneous polarity.

A9. The amplitude of the input signal is too large.

A10. The input impedance can be no higher than this value of resistance.

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greater drop appears across R_L. Thus, the increase in plate current is sustained as long as the input signal voltage exists at the corresponding level that caused the plate current to increase.

Q11. In Figure 44-10 what limits the signal amplitude?

44-11. Direct Coupled Amplifiers in Cascade

In each of the coupling circuits that have been considered so far, the coupling device isolates the dc voltage in the plate circuit of one tube from the grid circuits of the next tube; but they are designed to transfer the ac component with minimum attenuation.

In a direct coupled amplifier, on the other hand, the plate of one tube is connected directly to the grid of the next tube without going through a capacitor, a transformer, or any similar coupling device. This arrangement presents a problem of voltage distribution. Since the plate of a tube must have a positive voltage with respect to its cathode, and the grid of the next tube must have a negative voltage with respect to its cathode, it follows that the two cathodes cannot operate at the same potential. Proper voltage distribution is obtained by a voltage divider, as shown at A, B, C, D, and E in Figure 44-11.

In this amplifier the plate of V1 is connected directly to the grid of V2. The grid of V1 is returned to point A through R_{g1}. The

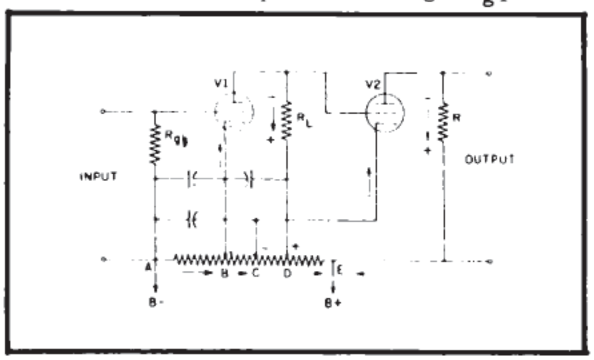

Figure 44-11 - Direct-coupled amplifier.

cathode of V1 is returned to point B. The grid bias for V1 is developed by the voltage drop between points A and B of the voltage divider. The plate of V1 is connected through its plate load resistor, R_L, to point D on the divider. R_L also serves as the grid resistor for V2.

Since the plate current from V1 flows through R_L, a certain amount of the supply voltage appears across R_L. The amount of voltage developed across R_L must be allowed for in choosing point D on the divider. Point D is so located that approximately half of the available voltage is applied to the plate of V1. The plate of V2 is connected through a suitable output load, R, to point E, the most positive point on the divider. Since the voltage drop across R_L may place too high a negative bias on the grid of V2, it may be necessary to connect the cathode of V2 at point C, which is negative with respect to point D, in order to lower the bias on the grid of V2 (since the voltages across R_L and CD are in opposition). Point C, together with the value of R, determines the proper voltage for V2.

The entire circuit is a complex resistance network that must be adjusted carefully to obtain the proper plate and grid voltages for both tubes. If more than two stages are used in this type of amplifier, it is difficult to achieve stable operation. Any small changes in the voltages of the first tube will be amplified and will thus make it difficult to maintain proper bias on the final tube connected into the circuit. Because of the instability thus encountered, direct coupled amplifiers are practically always limited to two stages. Furthermore, the power supply must be twice that required for one stage.

One method of supplying the range of voltage needed is to use a power supply which provides approximately equal amounts of both positive and negative voltages with respect to ground. This allows cascading without necessitating excessively high plate supply voltages. In Figure 44-11, either point C or point D might properly be tied to ground potential.

When the tube voltages are properly adjusted to give class A operation, the circuit serves as a distortionless amplifier whose response is uniform over a wide frequency range. This type of amplifier is especially effective at the lower frequencies because the impedance of the coupling elements does not vary with the frequency. Thus a direct coupled amplifier may be used to amplify very low frequency variations in voltage. Also, because the response is practically instantaneous, this type of coupling is useful for amplifying pulse signals where all distortion caused by the coupling elements must be avoided.

Q12. What is the primary advantage of a direct coupled amplifier compared to an RC coupled amplifier?

44-12. First Horizontal DC Amplifier

The first horizontal amplifier discussed will be a frequency-selective paraphase amplifier directly coupled to the output amplifier. The first dc amplifier is shown in Figure 44-12.

When the circuit is amplifying ac voltages or the internally generated sweep, the input to the grid of V106A comes from the ac horizontal gain control in the output of the cathode follower stage. In all the ac positions the cathode resistor R134 is bypassed to prevent degeneration.

When the circuit is amplifying dc voltages the input to the grid of V106A comes from the dc horizontal gain control.

The bias for V106A is equal to the voltage dropped across R134. The bias for V106B is the voltage dropped across R136. Under normal static conditions the dc plate voltage of V106A would be equal to the dc plate voltage of V106B. This would result in both deflection plates having equal positive dc voltages which would place the beam in the center of the CRT screen. By adjusting the horizontal centering control R136 the resultant bias on V106B can be changed. This causes a change of V106B dc plate voltage. The dc output voltage at point B can be changed in respect to the dc output voltage at point A, thereby providing a method of positioning the CRT beam at any desired horizontal position on the CRT screen. It should be remembered that a paraphase amplifier depends on an ac voltage divider network for proper operation. The operation of this amplifier is as follows.

The horizontal ac signal is coupled to the grid of V106A. An amplified ac is felt on the plate of V106A. This is the ac signal present at output A as shown in Figure 44-12. C119, R187 and R138 form an ac voltage divider. At low and medium frequencies the resistance ratio between R187 and R138 primarily determines the voltage division. The ac signal across R138 is very small at this time.

As the frequency applied to the horizontal channel is increased the reactance of C119 starts to shunt R187 resulting in more signal developing across R138. This signal across R138 is the input to V106B. The ac output of this stage (output at point B) is 180° out of phase with the output of V106A. Both output signals are riding equal dc reference levels but are not necessarily equal in amplitude. This unbalance in ac output amplitudes will be discussed later.

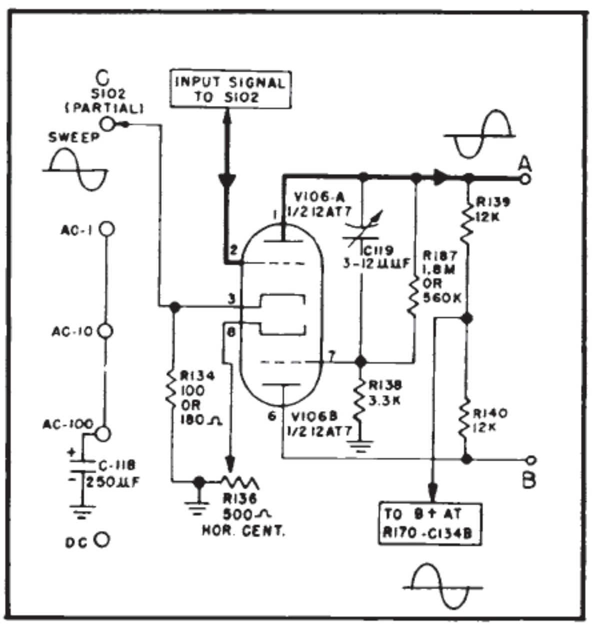

Figure 44-12 - First direct coupled amplifier.

Q13. How does the horizontal centering control R136 control the plate voltage of V106B?

44-13. Push-Pull Deflection

Balanced deflection is achieved when signals of equal amplitude but opposite phase are applied to both deflection plates. This is in contrast to single ended deflection where a signal is applied to one deflection plate and the other plate is at ground potential.

Most oscilloscopes employ push-pull amplifiers in the horizontal deflection channel to achieve push-pull deflection. In push-pull deflection using push-pull amplifiers, the amplitude of the driving signal required is one-half the amplitude of a signal required for single ended deflection systems. In Figure 44-13 where a dc voltage is used, the same results would be obtained if an ac signal were used.

In Figure 44-13 a ten volt signal is applied to the left deflection plate and the right deflection plate is grounded. This deflects the CRT beam one inch to the right. The same amount of deflection can be produced by applying one-half of this voltage, but of different polarity, to both plates. This is illustrated in Figure 44-14.

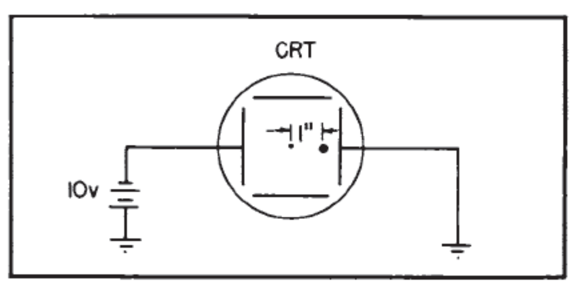

Figure 44-13 - Single ended deflection.

A11. The dc voltage input change cannot overcome and exceed the fixed bias E_C or distortion (grid current) would result.

A12. Extended low frequency response all the way down to dc (zero cps).

A13. By changing the cathode resistance and therefore the bias on V106B.

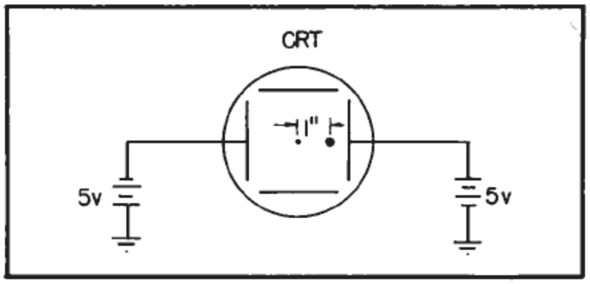

Figure 44-14 - Push-pull deflection.

This opposite polarity driving signal may be achieved by using a push-pull amplifier output stage, or a paraphase amplifier.

Q14. What is the primary advantage of push-pull deflection?

44-14. Second Horizontal DC Amplifier

A push-pull amplifier, with a paraphase amplifier driving it, is illustrated in Figure 44-15. This push-pull amplifier is not a conventional push-pull amplifier but is sometimes referred to as a cathode coupled push-pull amplifier.

The two control grids of the push-pull amplifier are directly coupled to the plates of the paraphase amplifier. Each grid is approximately 72 volts positive in respect to ground. The cathodes are tied together and connected to a common resistive network composed of R141 and R142. Since the plate load resistors are identical the quiescent currents through the tubes will be equal. The sum of these two currents will provide a cathode voltage of approximately 76 volts. This will give approximately minus 4 volts bias for each tube.

The bias control R141 is provided so that compensation for tolerances in resistors and electron tubes may be made in order to maintain the proper bias on the final stage. Proper adjustment of R141 is obtained when the voltage drop across the plate load resistors R145 and R146 is 90 volts, with the electron beam centered horizontally on the screen of the CRT.

The plates of V107A and V107B are connected directly to the horizontal deflection plates of the CRT.

The ac driving signal is directly coupled to the grid (pin 6) of V107A. For simplicity, a positive alternation of the horizontal ac signal at the plate of V106A (Figure 44-15) will be used. With a positive going signal applied, the plate current of V107A will increase, producing a negative going alternation of plate voltage and causing a positive voltage to be felt on the cathode. Since the cathode is common to both stages this rise will affect V107B. The grid of V107B is effectively at ac ground. The positive cathode

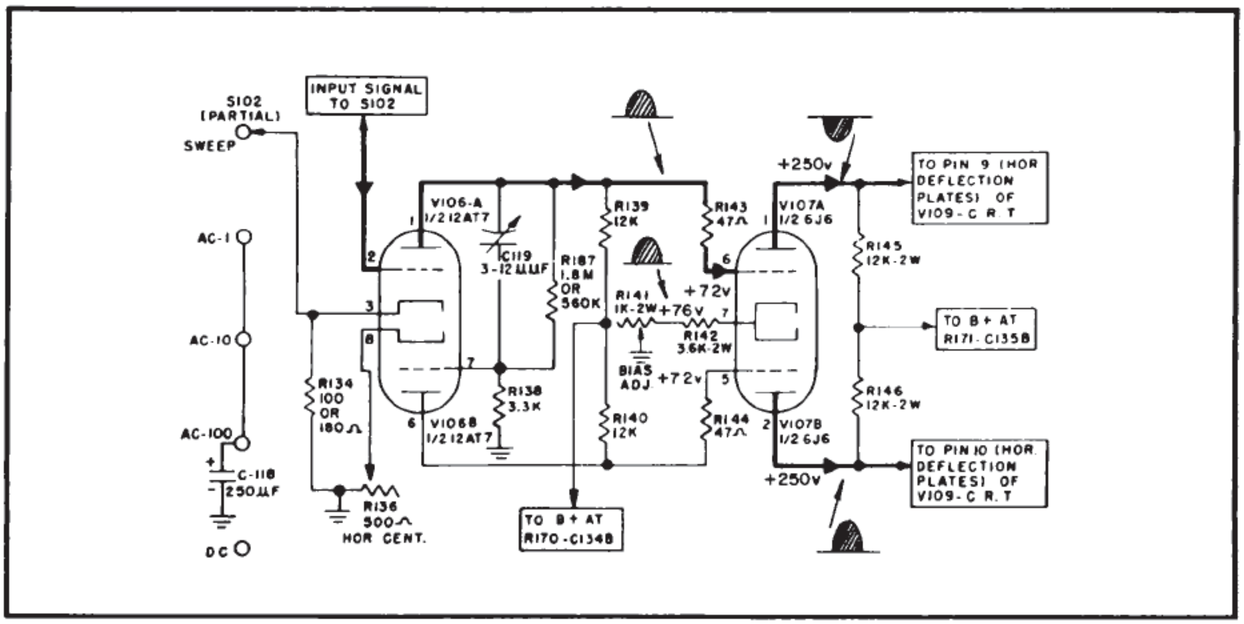

Figure 44-15 - First and second direct coupled amplifier.

voltage causes the same effect as a negative control grid. This action results in a decrease in the plate current of V107B and tends to reduce the cathode voltage drop. It should be evident that V107B's decrease in plate current is not equal to V107A's increase. If this were the case, there would not be a change of voltage across the cathode resistors.

This latter statement indicates that the change in plate current of V107A must always be more than the change in V107B's plate current. Since the plate load resistors and tubes are identical, the gain of V107A is the same as the gain of V107B. Therefore, the output voltage of V107A would be slightly larger than the output voltage of V107B because it has a larger signal applied.

To compensate for this unbalance in the push-pull amplifier, because of the cathode follower degenerative action and the degenerative action of the common cathode resistors, some signal is coupled into the grid of V107B from the paraphase amplifier. The amount of signal coupled is just enough to compensate for the losses in gain.

As the input frequency to the first and second dc amplifiers is increased, a loss of gain occurs due to the shunting effects of stray and interelectrode capacitance. To correct for this, more signal is coupled into V106B by the shunting effect of C119.

By not operating the push-pull amplifiers with driving signals of equal amplitude, at low and medium frequencies, the deflection sensitivity is less than maximum. The overall deflection sensitivity can be improved by approaching a condition of equal driving signals as the input frequency is increased. This counteracts the loss of gain due to shunting capacity at high frequencies and keeps the deflection sensitivity of the horizontal channel uniform over the frequency range of from one cps to 500 kc.

Since the circuit is push-pull any B+ variation caused by fluctuating line voltages has little or no effect on the centering of the beam of the CRT. This is because a dc voltage change on one deflection plate is accompanied by an equal voltage change on the other deflection plate.

Q15. Would the dc grid voltage of V107A be equal to the dc grid voltage of V107B under all conditions?

44-15. Horizontal Channel Used to Indicate DC Voltages

Figure 44-16 shows the input circuitry to the horizontal channel when the attenuator switch S102 is in the dc position.

When the horizontal channel is used to indicate dc voltages the input circuit to the first dc amplifier is modified and becomes a direct coupled

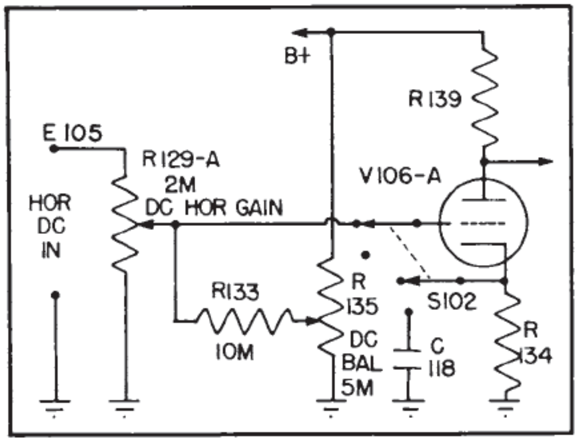

Figure 44-16 - DC voltage measurement.

input circuit. When the horizontal attenuator switch S102 is in the dc position there is a negative contact potential developed on the grid of V106A due to the high impedance of the horizontal dc gain control R129A. This condition is canceled by the selection of a positive potential by the horizontal dc balance control R135, which is in series with R133.

Improper adjustment of R135 will result in a shift of the electron beam with various settings of the horizontal gain control R129A. Proper adjustment of the horizontal balance control is made when rotation of the horizontal gain control has no effect on the position of the horizontal trace.

The dc voltage to be measured is developed across the horizontal gain control R129A. This potentiometer is used as a variable voltage divider. The voltage selected by the position of this control helps to bias the first dc amplifier V106A. This bias controls the dc plate voltage of V106A. Due to direct coupling V106A in turn controls the push-pull amplifier V107A which positions the beam on the CRT proportional to the dc input voltage.

44-16. Vertical Amplifiers

The vertical amplifier channel is shown in block diagram form in Figure 44-17.

There are two possible inputs both of which are external. In most cases, the signal to be viewed on the oscilloscope is applied to the vertical deflection amplifier. The specific signals that would be applied to the vertical channel is dependent on the type of equipment under test. The vertical channel provides two useful outputs. One is to the CRT for beam deflection and the other is sent to the sync. selector for the purpose of synchronizing the sweep generator with the vertical signal.

A14. Higher deflection sensitivity for the oscilloscope deflection channel.

A15. No. The dc grid voltages would only be equal if the beam were positioned in the center of the screen.

The ac input signal is coupled through the vertical attenuator to the vertical cathode follower. The dc input signal is coupled through the attenuator but bypasses the vertical cathode follower.

44-17. Vertical Attenuator

As in the horizontal channel the purpose of the vertical attenuator is to select the type and strength of signal fed into the vertical amplifier channel. The vertical amplifiers are fixed gain amplifiers and the output amplitude is adjusted by adjusting the input. The most common type of vertical attenuator employs a step-switch control. An ideal attenuator usually has a variable potentiometer for five amplitude adjustments. This potentiometer control is usually low in resistance and would tend to load down the attenuator if it were connected directly across the attenuator. For this reason, the potentiometer should have an impedance matching device between it and the attenuator. This impedance matching is accomplished by the use of a cathode follower stage.

44-18. Practical Attenuator

Figure 44-18 shows a practical vertical attenuator.

Section A of switch S101 selects the voltage divider to be used, and couples its output into the grid of the cathode follower stage. In the AC-1 position the ac signal receives no attenuation.

With S101 in positions AC-10 and AC-100, the input is attenuated by a factor of 10 and 100 respectively. The voltage divider networks have capacitors added for high frequency compensation as in the horizontal channel. With S101 in the dc position the ac input terminal J101 is grounded through C105. In all the ac positions section C of switch S101 connects C108 across the cathode resistor of the first dc amplifier and prevents cathode degeneration. Section D of switch S101 applies the output of the cathode follower stage to the first dc amplifier in the ac positions. In the dc position the input from terminal E102 is applied to the dc vertical gain control through section D of switch S101 of the first vertical dc amplifier.

44-19. Vertical Cathode Follower

Figure 44-19 shows a practical vertical channel cathode follower.

The operation of the vertical cathode follower is identical to that of the horizontal cathode follower discussed in section 44-5. Its main purpose is to provide an impedance match between low impedance of the ac gain control R104B and the attenuator network. The output of the cathode follower stage is sent through switch S101 section D in Figure 44-18 to the grid of the first dc amplifier.

DIRECT COUPLED VERTICAL AMPLIFIERS

44-20. First Direct Coupled Vertical Amplifier

Figure 44-20 shows the first and second dc vertical amplifiers.

The operation of the first vertical dc amplifier is essentially the same as the horizontal amplifier as discussed in paragraph 44-12. One primary difference, however, is the bias control of V102B. The cathode pin 8 is connected through R189 to B+.

This resistor and the vertical positioning control, R111, form a voltage divider network. The voltage drop across R111 is a resultant of

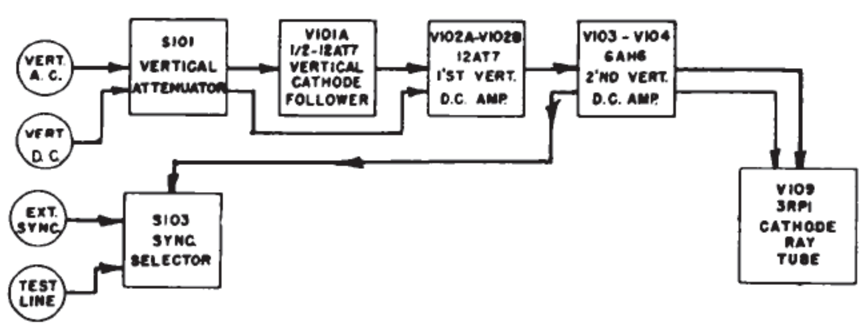

Figure 44-17 - Block diagram of vertical channel.

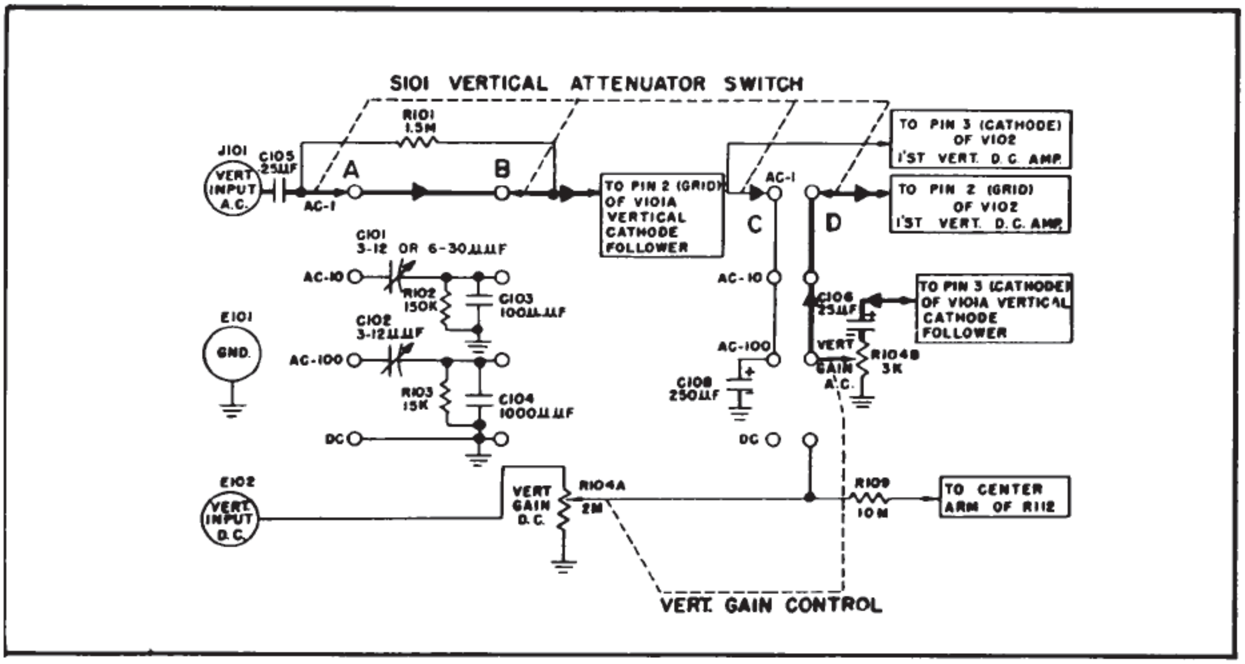

Figure 44-18 - Vertical input attenuator.

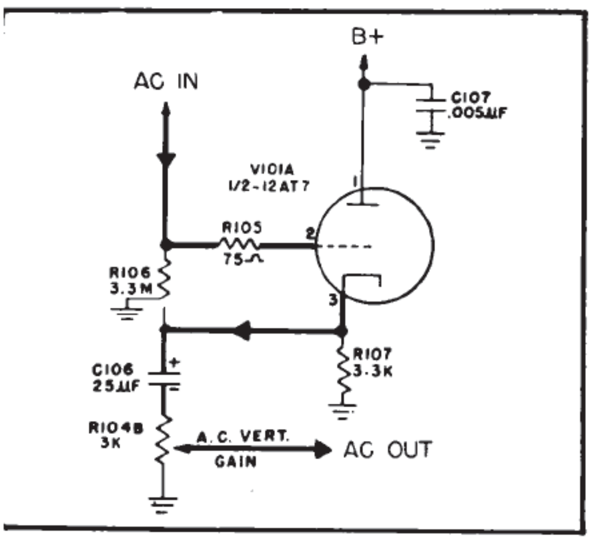

Figure 44-19 - Vertical cathode follower.

the sum of the divider current and normal tube current. This entire network provides a wider range of bias voltage available to V102-B when R111 is varied.

Capacitor C109 and R113 form a frequency sensitive ac voltage divider network. As the frequency applied to the vertical amplifiers is raised, more signal is developed across R113. The ac outputs of the first dc amplifier are 180° out of phase but not necessarily equal in amplitude. The first dc amplifier is directly coupled to the push-pull amplifier.

44-21. Second Direct Coupled Amplifier

The operation of the push-pull vertical amplifier is similar to the operation of the horizontal push-pull amplifier as discussed in section 44-14. The low values of plate load resistance (3.6K) are used, primarily, to increase the frequency response of the second d-c vertical amplifiers. The pentodes in this circuit will compensate for loss of gain due to the low value of plate load resistors. In addition, pentodes allow use of the screen grid for a linearity control. This particular circuit has an upper frequency response of approximately 2 Mc. Since the push-pull amplifiers are cathode coupled there is a driving signal developed across the common cathode resistor. This vertical signal is coupled from the cathodes of the push-pull amplifier for the purpose of synchronizing the sweep generator to the signal being viewed.

The bias adjustment potentiometer, R119, is provided to compensate for tolerances in resistors and electron tubes. Proper adjustment of R119 is obtained when the voltage drop across R123 or R124 in this circuit is 45 volts with the electron beam vertically centered on the cathode-ray tube.

The linearity adjustment R121 is incorporated in the circuit to adjust the voltage on the screen grids of the final push-pull amplifier. The linearity control is adjusted to provide an undistorted vertical presentation regardless of the trace placement (vertically) on the screen of the CRT.

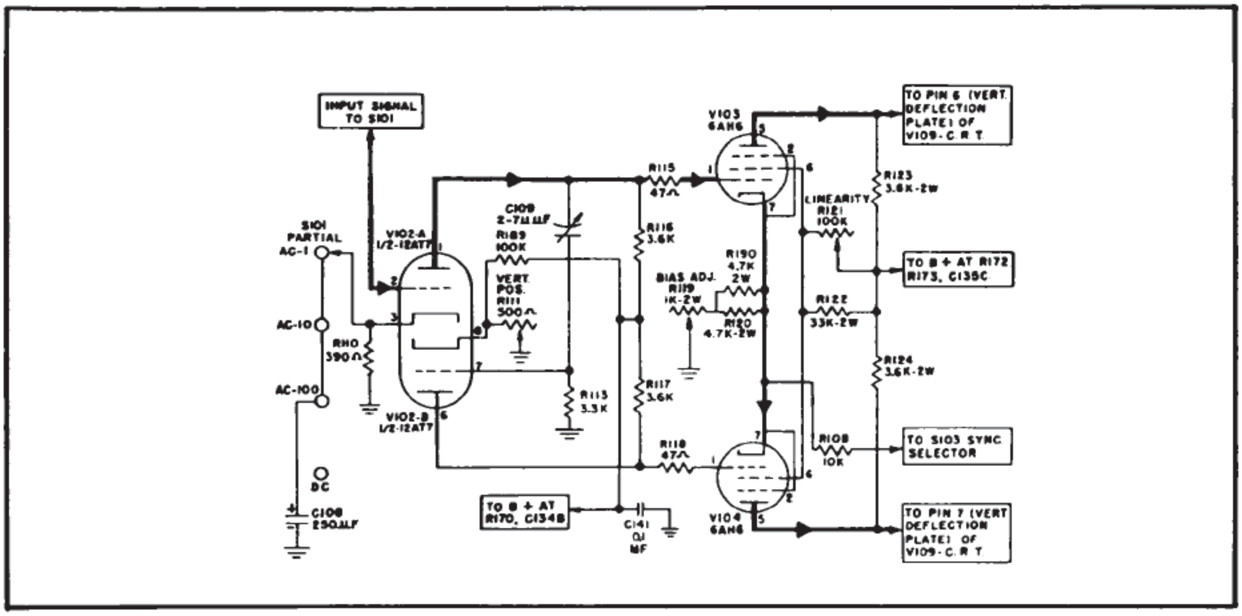

Figure 44-20 - Vertical amplifiers.

EXERCISE 44

1. Why do most attenuators employ high frequency compensation?
2. Why is the horizontal cathode follower not used when measuring dc voltages?
3. What would be the output of a cathode follower if the cathode resistor were bypassed?
4. What is the phase relationship between input and output signals of a cathode follower?
5. Why are direct coupled amplifiers usually limited to two stages?
6. Can the voltage gain of a cathode follower ever be greater than one? Why?
7. What is the primary advantage of push-pull deflection compared to single ended deflection systems?
8. How is positioning of the CRT beam accomplished?
9. What are the three possible inputs to the horizontal deflection channel?
10. What is a requirement of a power supply for a direct coupled amplifier?
11. Why are pentode tubes used in the vertical push-pull amplifiers?
12. What type of circuit is generally used to achieve push-pull deflection?
13. What are the current requirements of an output stage utilizing electrostatic deflection?
14. Why should the input impedance of the vertical deflection channel be high?
15. Why couldn't a sync signal be taken from the cathodes of the vertical push-pull amplifier if both tubes had equal grid signals?

CHAPTER 45

RC SHAPING CIRCUITS

For timing circuits and for circuits which require a sharp "spike" of voltage, SHAPING circuits may be used. By the use of shaping circuits, waveshapes such as square waves, sawtooth waves, and trapezoidal waves can be caused to change their shape. Shaping circuits may be either a series RC or a series RL circuit of a particular time constant in respect to the duration of the applied waveform. Notice that the waveshapes mentioned did not include the sine wave. The RC or RL shaping circuits CANNOT change the shape of a pure sine wave.

The series RC and RL circuits electrically perform the mathematical operations of INTEGRATION and DIFFERENTIATION. Therefore, the circuits used to perform these operations are called INTEGRATORS and DIFFERENTIATORS respectively. These names are given to these circuits even though they do not always completely perform the operations of mathematical integration and differentiation.

45-1. Composition of Nonsinusoidal Waves

Pure sine waves are basic waveshapes from which all other waveshapes can be constructed. Any waveform that is not a pure sine wave consists of two or more sine waves. By adding together the correct frequencies at the proper phase and amplitude, square waves, sawtooth waves and other nonsinusoidal waveforms can be obtained.

A waveform other than a sine wave is called a COMPLEX WAVE. It will be shown that a complex wave consists of a fundamental frequency plus one or more harmonic frequencies. The shape of a nonsinusoidal waveform is dependent upon the type of harmonics present as part of the waveform, their relative amplitudes, and their relative phase relationships. In general, the steeper the sides of a waveform, that is the more rapid its rise and fall, the more harmonics it contains.

The sine wave which has the same frequency as the complex periodic wave is called the FUNDAMENTAL FREQUENCY. The type and number of harmonics included in the waveform is dependent upon the shape of the waveform. There are two classifications for harmonics - even and odd. The harmonics are always a whole number of times higher than the fundamental, and are designated by an integer (whole number). For example, the frequency twice as high as the fundamental is the SECOND HARMONIC, or the first even harmonic.

Figure 45-1A compares a pure square wave with a sine wave, A, of the same frequency - its fundamental frequency. If another sine wave, B, of smaller amplitude but three times the frequency, called the third harmonic, is added to A, the resultant curve, C, is produced. The addition of these two waveforms is accomplished by adding the instantaneous values of both sine waves algebraically. The curve, C, is called the resultant, and begins to assume the shape of the square wave. The resultant of the addition of A and B, curve C, is again shown in Figure 45-1B.

When the fifth harmonic, curve D, is added, the sides of the new resultant, curve E, are

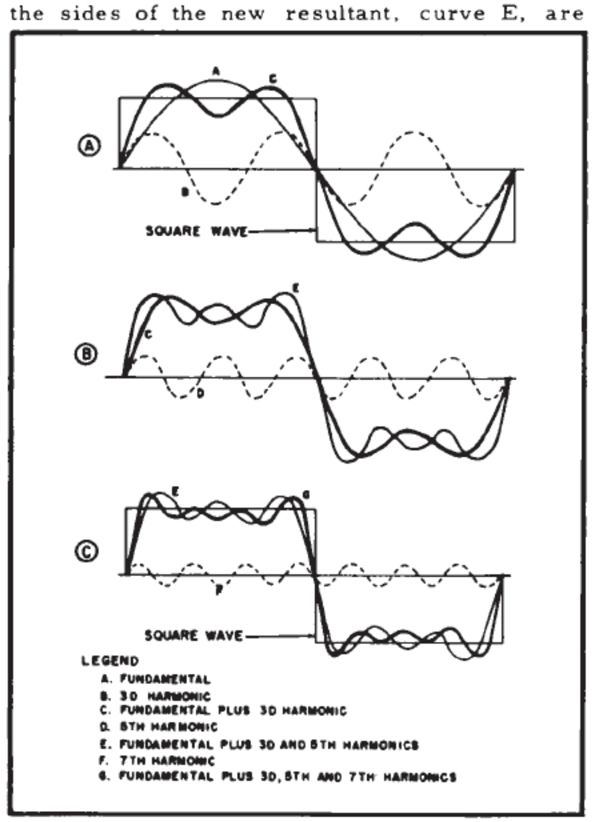

Figure 45-1 - Harmonic composition of a square wave.

steeper than before. Addition of the seventh harmonic, curve F, which is of smaller amplitude, makes the sides of the composite waveform steeper than any previous sine wave addition (Figure 45-1C). The addition of more odd harmonics will bring the composite waveform nearer the shape of the perfect square wave. A perfect square wave is composed of an infinite number of odd harmonics.

In the square wave composition, all the odd harmonics cross the zero reference line in phase with the fundamental.

Similarly, a sawtooth wave, shown in Figure 45-2, is made up of different harmonics. However, the sawtooth waveform contains both even and odd harmonics. The harmonic content of the sawtooth waveform is given in Figure 45-2. Notice that as each higher harmonic is added, the resultant more nearly resembles a sawtooth waveform.

Figure 45-3 shows the composition of a peaked wave. Notice how the addition of each odd harmonic makes the peak of the resultant higher and the sides steeper. The phase relationship between the harmonics of the peaked wave is different from the phase relationship of the harmonics in the square wave composition. In the square wave composition, all the odd harmonics cross the zero reference line in phase with the fundamental. In the peaked wave, harmonics

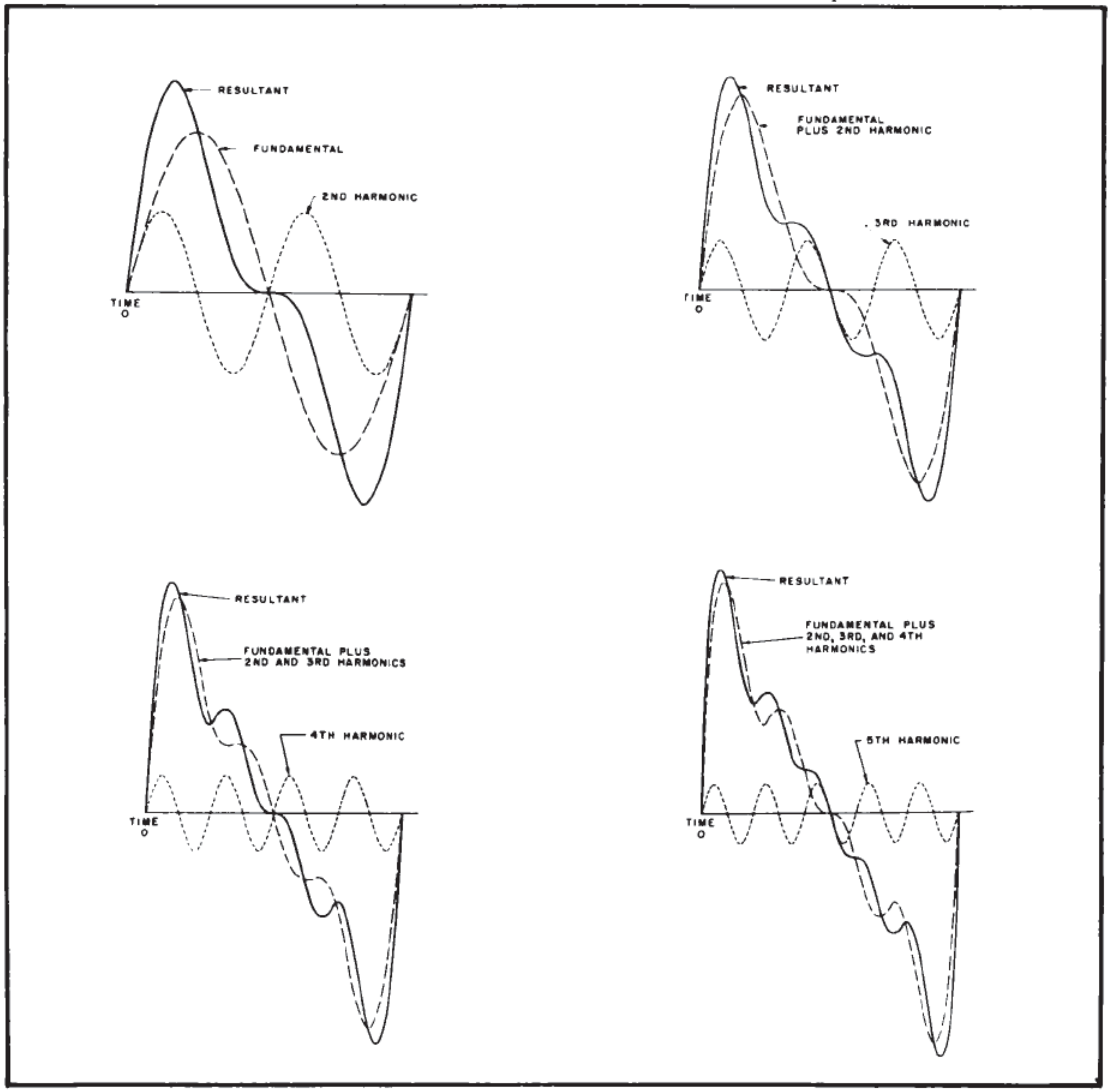

Figure 45-2 - Composition of a sawtooth wave.

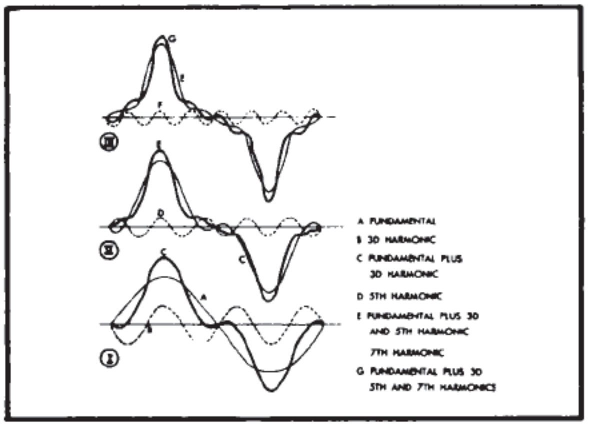

Figure 45-3 - Harmonic composition of a peaked wave.

such as the 3rd, 7th, etc., cross the zero line 180^o out of phase with the fundamental, while the 5th, 9th, etc. cross the zero line in phase with the fundamental.

Q1. What is the primary harmonic content of a square wave?

Q2. What is the peaked wave composed of?

Q3. What is the fundamental difference between the phase relationship of the harmonics of the square wave as compared to the harmonics of a peaked wave?

45-2. The RC Circuit as a Discriminator

To understand the principles of integration and differentiation, it is necessary to review the operation of the basic high frequency and low frequency discriminators. These circuits may also be called low pass or high pass filters. The high and low pass filters will be compared to the operation of an integrator and a differentiator because their operation is the same.

Figure 45-4 shows an RC circuit with 100 volts at 1 kc applied. With a capacitance of 0.0318 microfarad and a frequency of 1 kc, the capacitive reactance of the capacitor will be 5K. This means that at a frequency of 1 kc, there will be voltage drops across the resistor and the capacitor which will be equal to 70.7 volts. The

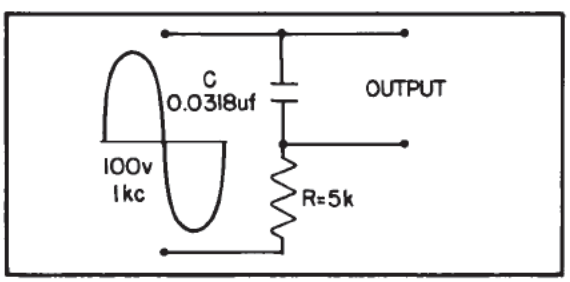

Figure 45-4 - RC discriminator circuit.

phase angle between the reference (I) and the applied voltage will be 45^o as shown in Figure 45-5.

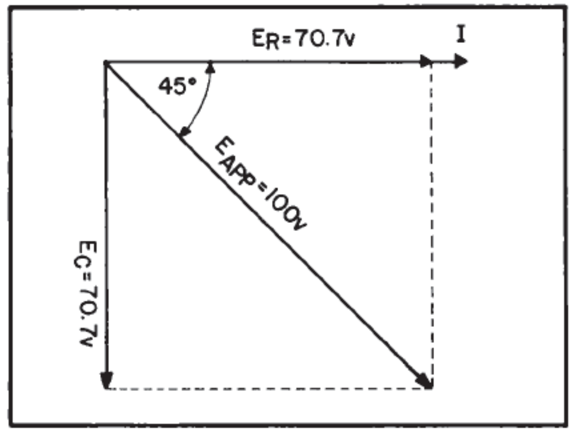

Figure 45-5 - Vector diagram.

In terms of discriminators, the 1 kc will be the cut-off frequency. The cut-off frequency may be defined as that frequency where the phase angle is 45^o, or that frequency where the voltage drops across the components are equal.

Assume that the output for the circuit is taken across the capacitor. Also assume that the frequency of the voltage applied is variable. When the frequency is increased to 5 kc, the capacitive reactance will decrease to a value of:

$$X_c = \frac{1}{2\pi f C}$$

$$X_c = \frac{1}{6.28 \times 5 \times 10^3 \times 3.18 \times 10^{-8}}$$

$$X_c = 1,000 \text{ ohms}$$

Computing the phase angle:

$$\theta = \arctan \frac{opp}{adj} = \frac{1}{5} = 0.2$$

$$\theta = 11.3^o$$

The vector diagram for this circuit is shown in Figure 45-6.

The voltage across the output capacitor will be:

$$E_C = E_{app} \times \sin \theta$$

$$E_C = 100 \times \sin 11.3$$

$$E_C = 100 \times 0.196$$

$$E_C = 19.6 \text{ volts}$$

A1. It is composed of odd harmonics.

A2. It is composed of odd harmonics.

A3. In the square wave, all the odd harmonics are in phase with the fundamental. This is not true of the odd harmonics in the peaked wave.

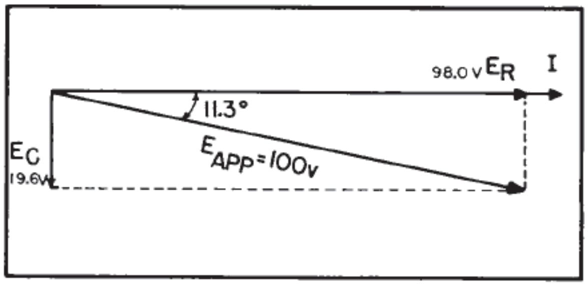

Figure 45-6 - Vector diagram.

The voltage across the resistor will be:

$$E_R = E_{app} \times \cos \theta$$

$$E_R = 100 \times \cos 11.3^o$$

$$E_R = 100 \times 0.980$$

$$E_R = 98.0 \text{ volts}$$

Since the phase angle dropped below 45° to 11.3°, the voltage across the capacitor is 19.6 volts; and the voltage across the resistor is 98.0 volts. Therefore, taking the output across the capacitor, the circuit is discriminating against the high frequencies. The term "discriminate" is used because the voltage across the output capacitor is an inverse function of frequency. It may also be said that the high frequencies are attenuated by the circuit.

If the frequency applied to the circuit decreases to 500 cps, the reactance offered by the capacitor would now be:

$$X_c = \frac{1}{2\pi f C}$$

$$X_c = \frac{1}{6.28 \times 5 \times 10^2 \times 3.18 \times 10^{-8}}$$

$$X_c = 10,000 \text{ ohms}$$

The phase angle will now be:

$$\theta = \arctan \frac{10}{5}$$

$$\theta = \arctan 2.0$$

$$\theta = 63.5^o$$

Computing voltages:

$$E_C = E_{app} \times \sin \theta$$

$$E_C = 100 \times \sin 63.5$$

$$E_C = 100 \times 0.895$$

$$E_C = 89.5 \text{ volts}$$

$$E_R = E_{app} \times \cos \theta$$

$$E_R = 100 \times \cos 63.5^o$$

$$E_R = 100 \times 0.446$$

$$E_R = 44.6 \text{ volts}$$

Under these conditions, the capacitor voltage is higher than the resistor voltage. If the output is taken from the capacitor, the circuit will pass the low frequencies, and discriminate against the high frequencies.

If the output were taken from across the resistor, the circuit would be a high pass circuit, or a low frequency discriminator.

Q4. What determines whether a circuit is a high or low frequency discriminator?

45-3. Nonsinusoidal Voltages Applied to a RC Circuit

The harmonic content of a square wave must be complete to produce a square wave. If the harmonics of the square wave are not of the proper phase and amplitude relationship as described in Section 45-1, the square wave will not be pure. The term pure as applied to square waves means that the waveform must be perfectly square to be a pure square wave.

Figure 45-7 shows a pure square wave applied to a series resistive circuit. If the values of the resistors are equal, the voltage drop

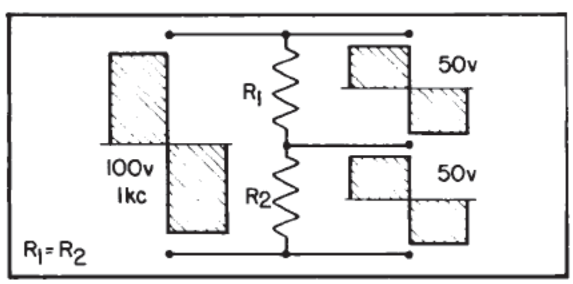

Figure 45-7 - Square wave applied to a resistive circuit.

across each resistor will be equal. From the one pure square wave input, two pure square waves of equal amplitude will be produced. The resistance of the resistors does not affect the phase or amplitude relationship of the harmonics contained in the square waves. This is true because the same opposition is offered by the resistors to all of the harmonics. However, if the same square wave is applied to a series RC circuit as shown in Figure 45-8, the action is not the same. Since the harmonic content of the square wave is odd multiples of the fundamental frequency, there will be significant harmonics as high as 50 or 60 times the frequency of the fundamental. The capacitor will offer a reactance of different magnitude to each of the harmonics. This means that the voltage drop across the capacitor for each harmonic frequency present will not be the same. To low frequencies, the capacitor will offer a large opposition providing a large voltage drop across the capacitor. To high frequencies, the reactance of the capacitor will be extremely small causing a small voltage drop across the capacitor. If the voltage component of the harmonic is not developed across the reactance of the capacitor, it will be developed across the resistor. Kirchhoff's voltage law must be observed. Since the harmonic amplitude and phase relationship across the capacitor is not the same as that of the original frequency input, it can hardly be expected that a perfect square wave will be produced across the capacitor. It must be remembered that the reactance offered to each harmonic frequency will not only cause a change in the amplitude of the harmonics, but will also cause a change in the phase of each individual harmonic frequency with respect to the current reference. The amount of phase and amplitude change taking place across the capacitor is dependent upon the capacitive reactance of the capacitor, which is a function of the capacitance. The value of the resistance offered by the resistor must also be considered here because it controls the ratio of the voltage drops across itself and the capacitor. If the voltage across the resistor and the capacitor are equal at some frequency, the phase angle will be equal to 45°. If the output is taken from across the capacitor, the circuit is a high frequency discriminator, or a low pass filter. If the output is taken from across the resistor, the circuit is a low frequency discriminator, or a high pass filter.

The circuit in Figure 45-9 will help show this more clearly. The square wave applied to the circuit is 100 volts peak at a frequency of 1 kc. The odd harmonics will be 3 kc, 5 kc, 7 kc, etc. Table 45-1 shows the value of the reactance offered to several of the harmonics and indicates the approximate value of the cut-off frequency. It can be seen from the table that the cut-off frequency lies between the fifth and the seventh harmonics. Between these two values, the capacitive reactance will equal the resistance. Therefore, all of the harmonic frequencies above the fifth will not be effectively dropped across the output capacitor. The absence of the higher order harmonics will cause the leading edge of the waveform developed across the capacitor to be rounded. An example of this effect is shown in Figure 45-10. If the value of the capacitance is increased, the reactances to each harmonic frequency will be decreased. This means that fewer harmonics will be developed across the capacitor.

HARMONIC	X_C	R
Fund.	159k	25k
3rd	53k	25k
5th	31.8k	25k
7th	22.7k	25k
9th	17.7k	25k
11th	14.5k	25k

Table 45-1. Resistance and Reactance Values

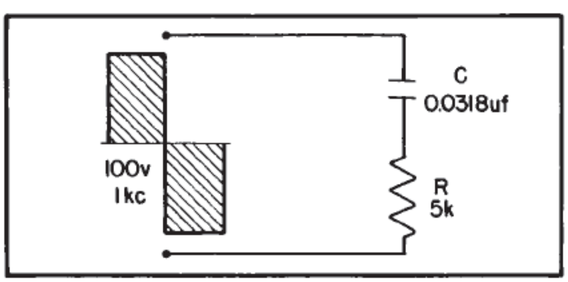

Figure 45-8 - Square wave applied to a RC circuit.

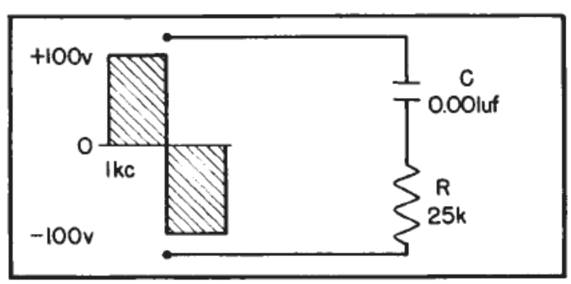

Figure 45-9 - Partial integration circuit.

A4. The characteristics of a discriminator are determined by where the output is taken.

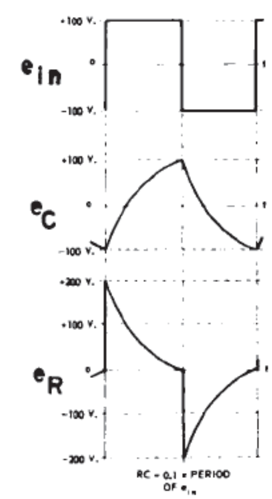

Figure 45-10 - Partial integration.

To satisfy Kirchhoff's voltage law, the harmonics not effectively developed across the capacitor must be developed across the resistor. If the waveform across both the resistor and the capacitor were added graphically, the resultant would be an exact duplication of the input square wave. Note the pattern of the voltage waveform across the resistor.

When the capacitance is increased sufficiently, full integration of the input signal takes place across the capacitor. An example of complete integration is shown in Figure 45-11 (waveform e_C). This effect was caused by decreasing the value of capacitive reactance. The same effect would take place by increasing the value of the resistance. Therefore, integration takes place in an RC circuit with the output taken across the capacitor.

Since the amount of integration is dependent upon the values of R and C, it may be said that the amount of integration is dependent upon the time constant of the circuit. To assure integration, the time constant of the circuit should be at least TEN TIMES GREATER than the time duration of the input pulse. In fact, the time constant should be greater than ten times the duration of the input pulse. The value of ten is only an approximation. When the time constant of the circuit is ten or more times the value of the duration of the input pulse, the circuit is said to possess a long time constant. When the time constant is long, the capacitor does not have the ability to charge instantly to the value

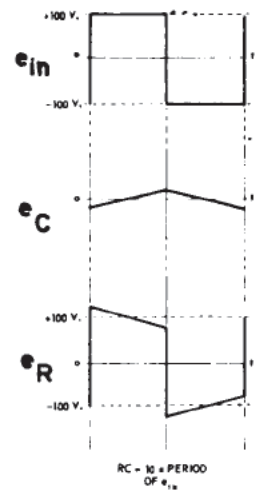

Figure 45-11 - Integration.

of the applied voltage. Therefore, the result is the long sloping integrated waveform.

Q5. What are the requirements for integration?

Q6. Can a pure sine wave be integrated? Why?

45-4. RL Circuit as an Integrator

The RL circuit may also be used as an integrating circuit. To obtain an integrated waveform from the series RL circuit, the output must be taken across the resistor. The characteristics of the inductor are such that at the first instant of time in which voltage is applied, the current flow through the inductor is minimum; and the voltage drop across it is maximum. Therefore, the value of the voltage drop across the series resistor at the same instant (first instant) of time must be zero volts because there is no current flow through it. However, as time passes, current begins to flow through the circuit; and voltage is developed across the resistor. Since the circuit also is a long time constant circuit, the voltage across the resistor will NOT respond to the rapid changes in voltage required by an input such as the square wave. Therefore, the conditions for integration with an RL circuit are a long time constant with the output taken across the resistor.

Q7. What characteristic of an RL circuit allows it to act as an integrator?

45-5. Integrator Waveform Analysis

If either an RC or RL circuit has a time constant ten times greater than the duration of the input pulse, the circuits are capable of inte-

gration. What now will be done will be to compute and graph the actual waveform that would result from a long time constant (10 times the pulse duration), a short time constant (one-tenth of the pulse duration), and a medium time constant (that time constant between the long and the short). To accurately plot values for the capacitor output voltage, the universal time constant chart shown in Figure 45-12 is used.

It is known that the capacitor charge follows the shape of the curve in Figure 45-12. This curve may be used to determine the amount of voltage across either component in the series RC circuit. As long as the time constant or a fractional part thereof is known, the voltage across either component may be determined. In Figure 45-13, a pulse of 100 microseconds duration at an amplitude of 100 volts will be applied to the circuit composed of the 0.01 uf capacitor and the variable resistor, R. The square wave applied is a symmetrical square wave. The resistance of the variable resistor will be set at a value of 1,000 ohms. The time constant of the circuit is given by:

$$T = RC$$

Substituting values:

$$T = 1 \times 10^{3} \times 1 \times 10^{-8}$$

$$T = 10 \text{ microseconds}$$

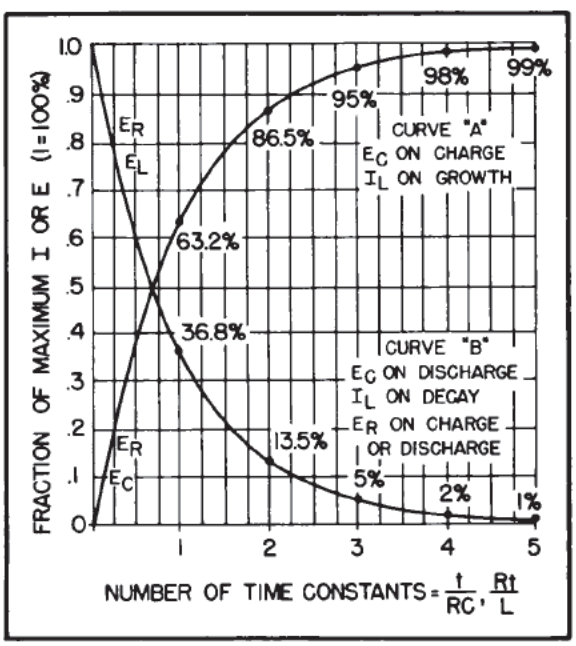

Figure 45-12 - Universal time constant chart.

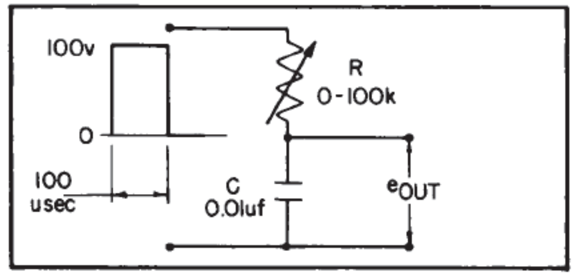

Figure 45-13 - RC integrator circuit.

Since the time constant of the circuit is 10 microseconds, and the pulse duration is 100 microseconds, the time constant is short (1/10 of the pulse duration). The capacitor will charge exponentially through the resistor. In five time constants the capacitor will be, for all practical purposes, completely charged. At the first time constant, the capacitor will be charged to 63.2 volts, at the second 86.5 volts, at the third 95 volts, at the fourth 98 volts; and finally at the end of the fifth time constant (50 microseconds) the capacitor is fully charged. This is shown in the graph in Figure 45-14.

Notice that the leading edge of the square wave taken across the capacitor is rounded. If the time constant were made extremely short, the rounded edge would become square.

To change the time constant, the variable resistor in Figure 45-13 will be increased to a value of 10,000 ohms. The time constant will now be equal to 100 microseconds.

This time constant is known as a medium time constant. Its value lies between the extreme ranges of the short time constant and the long time constant, and, in this case, happens to be exactly equal to the duration of the input pulse - 100 microseconds. A graph of the output waveform is shown in Figure 45-15. The

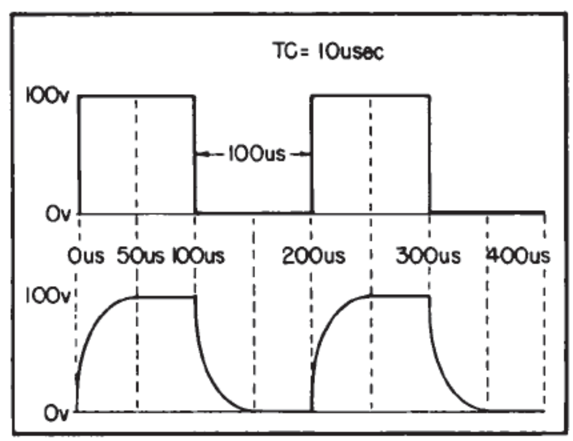

Figure 45-14 - Square wave applied to a short time constant (integrator).

A5. The time constant must be long, and the output for the circuit must be taken across the capacitor.

A6. A pure sine wave cannot be integrated because it does not contain harmonics.

A7. The ability of the inductor to oppose a change in current.

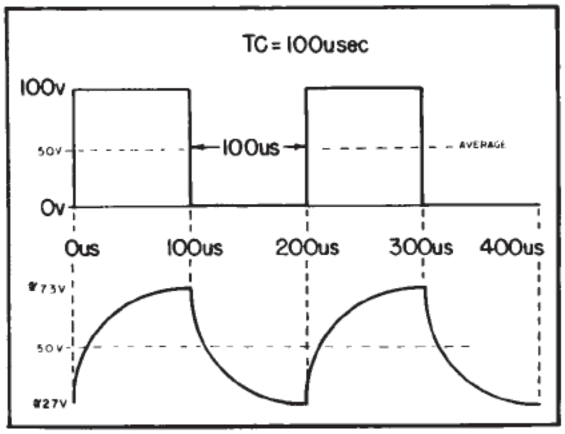

Figure 45-15 - Medium time constant (integrator).

long sloping rise and fall of voltage is because of the capacitors inability to charge and discharge rapidly through the 10,000 ohm series resistance.

At the first instant of time, one hundred volts is applied to the medium time constant circuit. One time constant is exactly equal, in this circuit, to the duration of the input pulse. After one time constant, the capacitor will charge to 63.2% of the input voltage (100 volts). Therefore, at the end of one time constant (100 microseconds) the voltage across the capacitor is equal to 63.2 volts. However, as soon as 100 microseconds has elapsed, and the initial charge on the capacitor has risen to 63.2 volts; the input voltage suddenly drops to zero, where it remains for 100 microseconds. The capacitor will now discharge for 100 microseconds. Since the discharge time is 100 microseconds (one time constant), the capacitor will discharge 63.2% of its total 63.2 volt charge - to a value of 23.3 volts. During the next 100 microseconds, the input voltage will increase from zero to a 100 volts very rapidly. The capacitor will now charge for 100 microseconds (one time constant). The voltage available for this charge is the difference between the voltage applied and the charge on the capacitor (100 - 23.3), or 76.7 volts. Since the capacitor will only be able to charge for one time constant, it will charge to 63.2% of the 76.7 volts, or 48.4 volts. The total charge on the capacitor at the end of 300 microseconds will be 23.3 + 48.4, or 71.7 volts.

Notice that the capacitor voltage at the end of 300 microseconds is greater than the capacitor voltage at the end of 100 microseconds. The voltage at the end of 100 microseconds is 63.2 volts, and the capacitor voltage at the end of 300 microseconds is 71.7 volts - an increase of 8.5 volts.

The output waveform in this graph (Fig. 45-15) is the waveform realized after many cycles of input signal to the integrator. The capacitor charges and discharges in a step-by-step manner until, finally, the capacitor will charge and discharge above and below a fifty volt level as shown in Figure 45-15. The fifty volt level is governed by the maximum amplitude of the symmetrical input pulse, the average value of which is fifty volts.

If the resistance in the circuit of Figure 45-13 is increased to 100,000 ohms, the time constant of the circuit will be 1,000 microseconds. This time constant is ten times the pulse duration of the input pulse. It is, therefore, a long time constant circuit.

The shape of the output waveform across the capacitor is shown in Figure 45-16. The shape of the output waveform is characterised by a long sloping rise and fall of capacitor voltage.

At the first instant of time, one hundred volts is applied to the long time constant circuit. One time constant is equal to ten times the duration of the input pulse.

To determine the value of charge on the capacitor at the end of the first 100 microseconds of the input signal, the universal time constant chart must be consulted. On the time constant chart, the percentage of voltage corresponding to 1/10 (100 microseconds/1000 microsec-

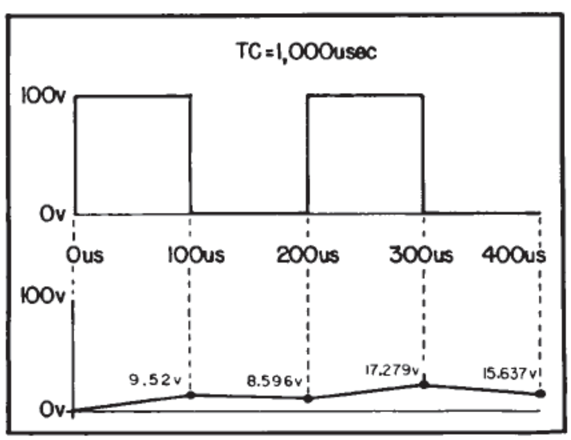

Figure 45-16 - Square wave applied to a long time constant circuit.

onds) of a time constant is found. If a line is projected up from the point on the base line corresponding to 1/10 of a time constant, to where it intersects the time constant chart, the percentage of voltage across the capacitor at the end of the first 100 microseconds can be found. Since the applied voltage is 100 volts, the charge on the capacitor at the end of the first 100 microseconds will be 9.5 volts. At the end of the first 100 microseconds, the input signal will fall suddenly to zero; and the capacitor will discharge. It will be able to discharge for 100 microseconds. Therefore, the capacitor will discharge 9.5% of its accumulated 9.5 volts, or (9.5% x 9.5) = 0.9045 volts. The loss of the 0.9045 volts will result in a remaining charge on the capacitor of 8.596 volts. At the end of 200 microseconds, the input signal will again suddenly rise to a value of 100 volts. The capacitor will be able to charge to 9.5% of the difference (100 - 8.596 = 91.404 volts), or to a value of 8.683 volts plus the initial 8.596 volts will result in a total charge on the capacitor at the end of the first 300 microseconds of 8.683 + 8.596 = 17.279 volts.

Notice that the capacitor voltage at the end of the first 300 microseconds is greater than the capacitor voltage at the end of the first 100 microseconds. The voltage at the end of the first 100 microseconds is 9.5 volts, and the capacitor voltage at the end of the first 300 microseconds is 17.279 volts — an increase of 7.779 volts.

The capacitor charges and discharges in a step-by-step manner until, finally, the capacitor will charge and discharge above and below a fifty volt level. The fifty volt level is governed by the maximum amplitude of the symmetrical input pulse, the average value of which is fifty volts.

Q8. What is the numerical difference between a long and a short time constant circuit?

Q9. What would happen to the integrator output if the capacitor were made extremely large (all other factors remaining the same)?

45-6. Differentiation

Differentiation is the direct opposite of integration. In the RC integrator, the output is taken from the capacitor. In the differentiator, the output is taken across the resistor. This, of course, means that when the RL circuit is used as a differentiator, the differentiated output is taken across the inductor.

An application of Kirchhoff's law shows the relationship between the waveforms across the resistor and capacitor in a series network. Since the sum of the voltage drops in a closed loop must equal the applied voltage, the graphical sum of the voltage waveforms in a closed loop must equal the applied waveform. Figure 45-17 shows the output taken across the variable resistor.

With the variable resistor set at 1,000 ohms, and the capacitor value of 0.01 microfarad, the time constant of the circuit will be 10 microseconds. Since the input waveform has a duration of 100 microseconds, the circuit is a short time constant circuit.

In the short time constant circuit at the first instant of time, the voltage across the capacitor is zero; and the current flow through the resistor will cause a maximum voltage to be developed across it. This is shown at the first instant of time in the graph of Figure 45-18.

As the capacitor begins assuming a charge, the voltage drop across the resistor will begin to decrease. At the end of the first time constant, the voltage drop across the resistor will have decreased by a value equal to 63.2% of the applied voltage. Since there is 100 volts applied, the voltage across the resistor after one time

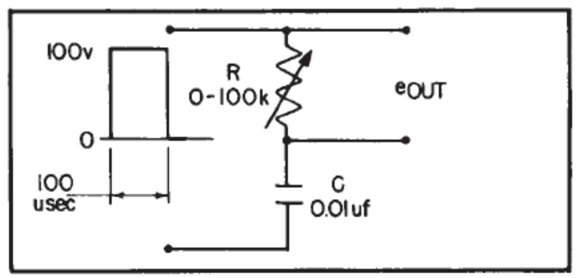

Figure 45-17 - RC circuit as a differentiator.

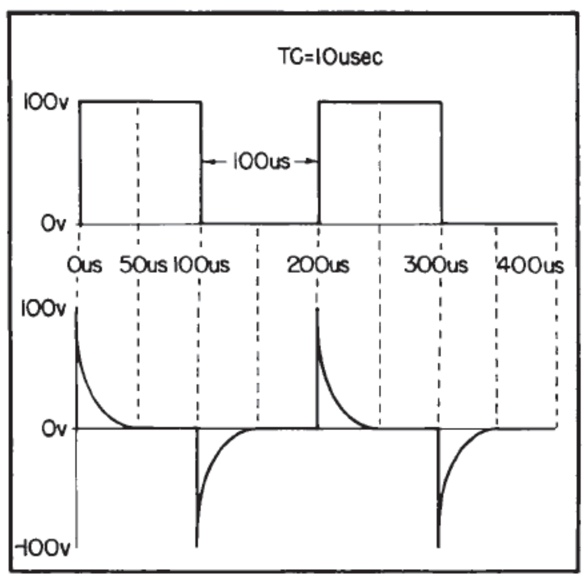

Figure 45-18 - Square wave applied to a short time constant circuit.

A8. Numerically, the time constant value of a long time constant circuit is ten times the value of the pulse duration. The short time constant circuit has a time constant equal to, or less than, one-tenth the duration of the input pulse.

A9. A more complete integration of the input waveform would result due to the increased time constant of the circuit.

---

constant will be equal to 36.8 volts. After the second time constant, the voltage across the resistor will be down to 13.5 volts. At the end of the third time constant, E_R will be 5 volts, and at the end of the fourth time constant, 2 volts. At the end of the fifth time constant, the voltage across the resistor will be very close to zero volts. Since the time constant is equal to 10 microseconds, it will take a total of 50 microseconds to completely charge the capacitor.

As shown in Figure 45-18, the slope of the charge curve will be very sharp. The voltage across the resistor will remain at zero volts until the end of 100 microseconds. At that time, the applied voltage suddenly drops to zero, and the capacitor will now discharge through the resistor. At this time, the discharge current will be maximum causing a large discharge voltage drop across the resistor. This is shown as the negative spike in Figure 45-18. Since the current flow from the capacitor, which now acts like a source, is decreasing exponentially, the voltage across the resistor will also decrease. The resistor voltage will decrease exponentially to zero volts in five time constants. All of this discharge action will take a total 50 microseconds. The discharge curve is also shown in Figure 45-18. After the end of 200 microseconds, the action begins again. The output waveform taken across the resistor in this short time constant circuit is an example of differentiation. With the square wave applied, the output is positive and negative spikes. These spikes approximate the rate of change of the input square wave.

The output across the resistor in an RC circuit of medium time constant is shown in Figure 45-19. The value of the variable resistor has been increased to a value of 10,000 ohms. This means that the time constant of the circuit is equal to the duration of the input pulse — 100 microseconds. For clarity, the voltage waveforms developed across both the resistor and the capacitor are shown. At all times, the sum of the voltages across the resistor and capacitor must be equal to the applied voltage of 100 volts.

At the first instant of time, a pulse of 100

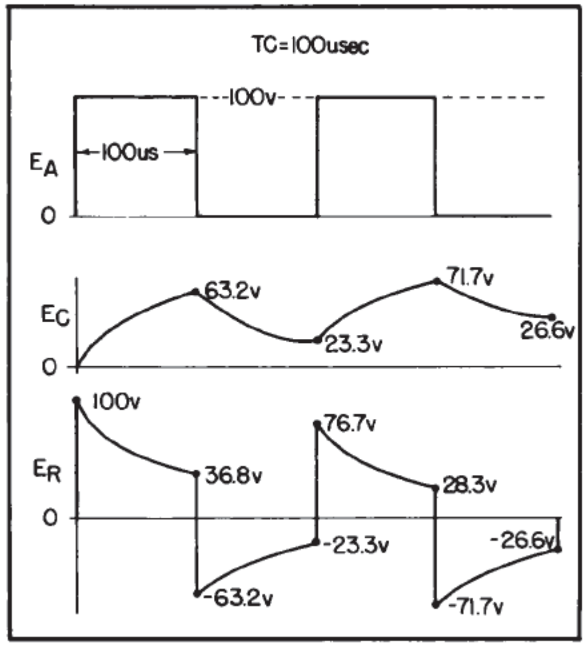

Figure 45-19 - Voltage outputs in a medium time constant circuit.

volts in amplitude at a duration of 100 microseconds is applied. Since the capacitor cannot respond quickly to the change in voltage, all of the applied voltage is felt across the resistor. Figure 45-19 shows the voltage across the resistor, E_R, to be 100 volts; and the voltage across the capacitor, E_C, to be zero volts at this time. As time progresses, the capacitor will charge. As the capacitor voltage increases, the resistor voltage will decrease. Since the time that the capacitor is permitted to charge is 100 microseconds (equal to one time constant in this circuit), the capacitor will charge to 63.2% of the applied voltage at the end of one time constant, or 63.2 volts. Because Kirchhoff's law must be adhered to at all times, the voltage across the resistor must be equal to the difference between the applied voltage and the charge on the capacitor (100 - 63.2), or 36.8 volts.

At the end of the first 100 microseconds, the input voltage suddenly drops to zero volts, a change of 100 volts. Since the capacitor is not able to respond to so rapid a voltage change, the 100 volt change must occur across the resistor. The voltage across the resistor must, therefore, reverse polarity and attain a magnitude of -63.2 volts. The capacitor now acts as a source and the sum of the voltage across the two components is now zero.

During the next 100 microseconds, the capacitor discharges. To maintain the total voltage at zero, the voltage across the resistor must decrease at exactly the same rate. This ex-

ponential decrease in resistor voltage is shown in Figure 45-19 during the second 100 microseconds. Since the capacitor will discharge 63.2% of its charge, to a value of 23.3 volts, at the end of the second 100 microseconds, the resistor voltage must rise, in the positive direction, to a value of -23.3 volts in order to maintain the total voltage at zero volts.

At the end of 200 microseconds, the input voltage again rises suddenly to 100 volts. Since the capacitor cannot respond to the 100 volt increase instantaneously, the 100 volt change takes place across the resistor. The voltage across the resistor suddenly rises from -23.3 volts to +76.7 volts. The capacitor will now begin to charge for 100 microseconds thus decreasing the voltage across the resistor. This charge and discharge action will continue for many cycles. Finally, the voltage across the capacitor will rise and fall, by equal amounts, about a fifty volt level. The resistor voltage will also rise and fall, by equal amounts, about a zero volt level.

If the time constant for the circuit in Figure 45-17 is increased to make it a long time constant circuit, the differentiator output will appear more like the input. The time constant for the circuit can be changed by either increasing the value of capacitance or resistance. In this circuit the time constant will be increased by increasing the value of resistance from 10K to 100K. This will result in a time constant of 1000 microseconds. This time constant is ten times the duration of the input pulse. The output of this long time constant circuit is shown in Figure 45-20.

At the first instant of time, a pulse of 100 volts amplitude at a duration of 100 microseconds is applied. Since the capacitor cannot respond instantaneously to a change in voltage, all of the applied voltage is felt across the resistor. As time progresses, the capacitor will charge and the voltage across the resistor will be reduced. Since the time that the capacitor is permitted to charge is 100 microseconds, the capacitor will charge for only 1/10 of one time constant, or to 9.5% of the applied voltage (as found using the universal time constant chart). Because Kirchhoff's law must be observed, the voltage across the resistor must be equal to the difference between the applied voltage and the charge on the capacitor (100 - 9.5, or 90.5 volts.

At the end of the first 100 microseconds of input, the applied voltage suddenly drops to zero volts, a change of 100 volts. Since the capacitor is not able to respond to so rapid a voltage change, the 100 volt change must occur across the resistor. The voltage across the resistor must, therefore, reverse polarity and attain a magnitude of -9.5 volts. The sum of the

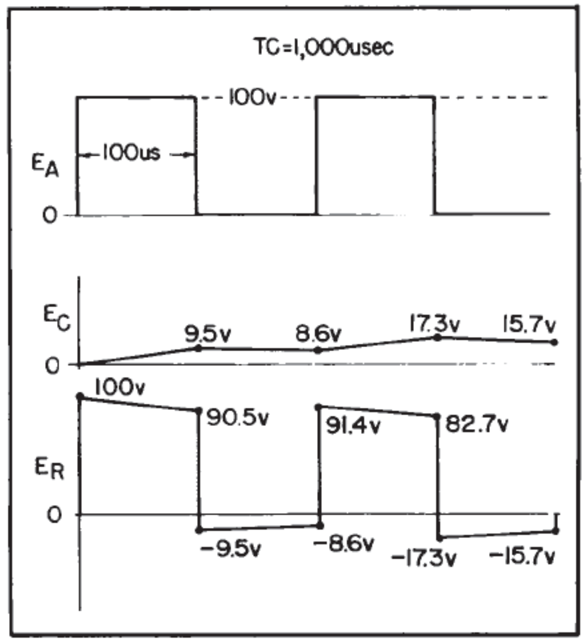

Figure 45-20 - Long time constant circuit with square wave applied.

voltage across the two components is now zero.

During the next 100 microseconds, the capacitor discharges. To maintain the total voltage at zero, the voltage across the resistor must decrease at exactly the same rate as the capacitor discharge. This exponential decrease in resistor voltage is shown in Figure 45-20 during the second 100 microseconds of operation. Since the capacitor will now discharge 9.5% of its charge, to a value of 8.6 volts, at the end of the second 100 microseconds, the resistor voltage must rise, in a positive direction, to a value of -8.6 volts in order to maintain the total voltage at zero volts.

At the end of 200 microseconds, the input voltage again suddenly rises to 100 volts. Since the capacitor cannot respond to the 100 volt change instantaneously, the 100 volt change takes place across the resistor. This step-by-step action will continue until stabilization. After many cycles have passed, the capacitor voltage varies above and below, by equal amounts, the fifty volt level. The resistor voltage varies above and below, by equal amounts, a zero volt level.

The RC networks which have been discussed in this chapter may also be used as coupling networks. When an RC circuit is used as a coupling circuit, the output is taken from across the resistor. Normally, a long time constant circuit is used. This, of course, will cause an integrated waveshape across the capacitor if

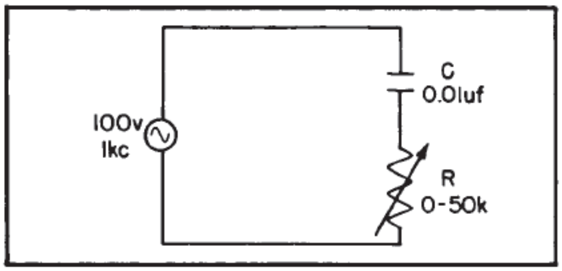

Figure 45-21 - Phase shifter.

the applied signal is nonsinusoidal. However, in a coupling circuit, the signal across the resistor should closely resemble the input signal, and it will if the time constant is sufficiently long. If the diagram in Figure 45-20 is referred to, it can be seen that the voltage across the resistor closely resembles the input signal.

If a pure sine wave is applied to a long time constant RC circuit (R is much greater than X_C), a large percentage of the applied voltage will be dropped across the resistor, and a small amount of voltage will be dropped across the capacitor.

Q10. What is the difference between an RC and an RL differentiator?

45-7. Phase Shifter

In ordinary coupling circuits, a phase shift is usually undesirable. In some circuits, such as oscillators, a phase shift of a definite angle is required. A phase shift may be obtained by use of either the series RC or the series RL circuit. When a circuit is used to change the phase relationship between the input and output voltage, the circuit is known as a PHASE SHIFTER. An example of an RC circuit used as a phase shifter is shown in Figure 45-21.

In the diagram of Figure 45-21, a pure sine wave of 100 volts in amplitude, at a frequency of 1,000 cps is applied to a series RC circuit. The value of capacitive reactance is calculated and found to be 15,900 ohms.

If the variable resistor is set to a value equal to X_C, the phase shift between the input voltage and the resistor voltage will be 45° as shown in Figure 45-22. Notice that the resistor voltage is 70.7 volts and leads the input voltage by 45°.

If the variable resistor is set to a value of 2 X_C (31,800 ohms), the phase angle will decrease to a value of 26.6° as shown in Figure 45-23. The resistor voltage has increased to 89.4 volts, but the phase difference between the input and the resistor voltage has decreased to 26.6°.

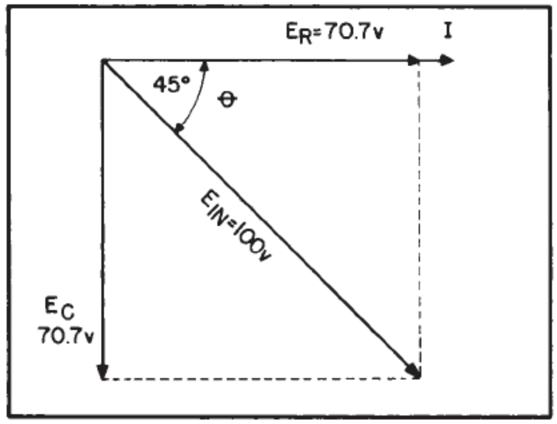

Figure 45-22 - Vector diagram.

The phase angle and resistor voltage may be calculated for any value of resistance using the following formula:

$$\theta = \arctan X_C/R$$
$$E_R = E_{in} \times \cos \theta$$

The phase angle, θ, will change if the resistance, capacitance, or frequency changes. A decrease in resistance, capacitance, or frequency will increase the phase shift if the output is taken from the resistor.

A phase shift of this type is not accomplished without some loss. The greater the phase shift, the smaller the output will become.

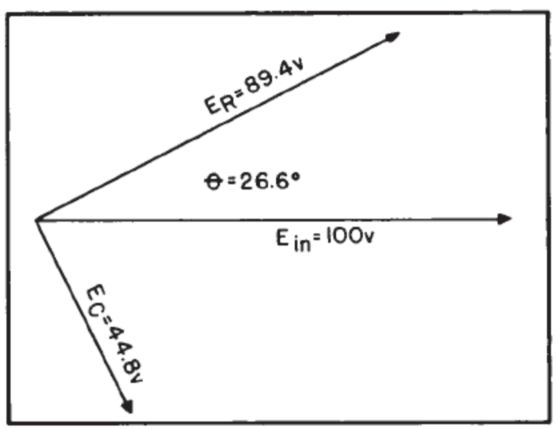

Figure 45-23 - Vector diagram.

EXERCISE 45

1. Describe the primary harmonic content of a pure sine wave, peaked wave, square wave and sawtooth wave.
2. Describe what happens to a square wave if its third harmonic and fifth harmonics are removed.
3. What is the difference between the phase relationships of the harmonics in a square wave and a peaked wave?
4. Which one of the waveforms described in this chapter contains both even and odd harmonics?
5. Describe the operation of the RC discriminator.
6. Describe the operation of an RL circuit used as a high frequency discriminator.
7. Describe the operation of an RC circuit used as a high pass filter.
8. What is meant by the term "cut-off frequency?
9. What is a nonsinusoidal waveform?
10. What characteristics of an inductor permits its use as an integrator?
11. What is the condition for complete integration?
12. A pulse of 200 microseconds is applied to an RC circuit the capacitance value of which is 0.1 uf, and the resistance value is 2k ohms. The output is taken across the capacitor. Describe the type of waveform and draw its output waveform.
13. Replace the capacitor in problem 12 with a 20 mh choke, take the output across it and draw the output waveform.
14. Compare the circuits which may be used for differentiation and integration.
15. What is the difference between integration and differentiation?
16. Describe the action of the RL differentiator, draw the outputs across each component. Use the values L = 12 mh, and R = 20 ohms.
17. Describe the conditions necessary for integration and differentiation.
18. What is a phase shifter?
19. If a series RC circuit C = 0.002 uf, R = 30,000 ohms, f = 1.5 kc, is used as a phase shifter, find the value of the phase difference between the applied voltage and the output voltage. Assume that the output is taken across the resistor.
20. What is the difference between a symmetrical and non-symmetrical square wave?

A10. In the RC circuit, the output is taken across the resistor. In the RL circuit, the output is taken across the inductor.

CHAPTER 46

RC OSCILLATOR CIRCUITS

In previous chapters, a number of different types of oscillators have been discussed. Some of these oscillators generate sine waves, while others produce non-sinusoidal waves such as square waves and sawtooth waves. Each of the sine wave oscillators discussed previously utilizes regenerative feedback and a tank circuit containing inductance and capacitance to generate the sine wave. In this chapter, two additional sine wave oscillators of the regenerative feedback type will be discussed. These oscillators are unique, in that no tank circuit is required to generate the sine wave.

WIEN BRIDGE OSCILLATOR

46-1. General Characteristics

The Wien-bridge oscillator consists of a two stage, RC coupled amplifier, in which regenerative feedback is coupled from the plate of the second stage to the grid of the first stage, as shown in Figure 46-1. To insure that positive feedback of the proper amplitude occurs at one frequency only, a frequency selective RC filter circuit is placed in series with the feedback path. Since this filter circuit determines the frequency of the feedback, the oscillator can be adjusted to the desired operating frequency by selecting the proper values of resistance and capacitance for the filter circuit.

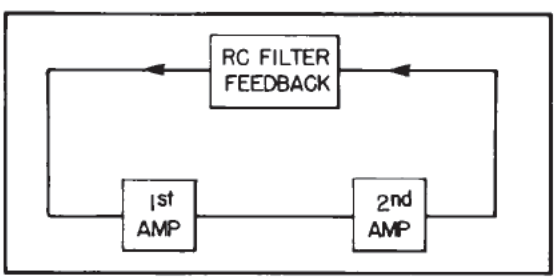

Figure 46-1 - Wien-bridge block diagram.

Due to its method of operation, the Wien-bridge oscillator is capable of generating an exceptionally pure sine wave of very low harmonic content. For this reason, it is often used in test equipment as an audio frequency signal generator. In addition to purity of waveform, the Wien-bridge oscillator is also noted for its frequency and amplitude stability.

Because an RC coupled amplifier forms part of the oscillator circuit, the maximum frequency of operation is limited by the high frequency response of the coupling network. Normally the oscillator is used for audio frequencies and low RF frequencies up to several hundred kilocycles.

Q1. What major difference exists between the feedback circuit of a Wien-bridge oscillator and the feedback network of a conventional LC oscillator?

46-2. Circuit Operation

The circuit illustrated in Figure 46-2 is a free-running multivibrator whose output is a square wave. The circuit oscillates because of the regenerative feedback coupled to the grid of V_1 by capacitor C_2 and to the grid of V_2 by capacitor C_1. The frequency of the square wave output is determined mainly by the time constants of the coupling capacitors and their associated resistors.

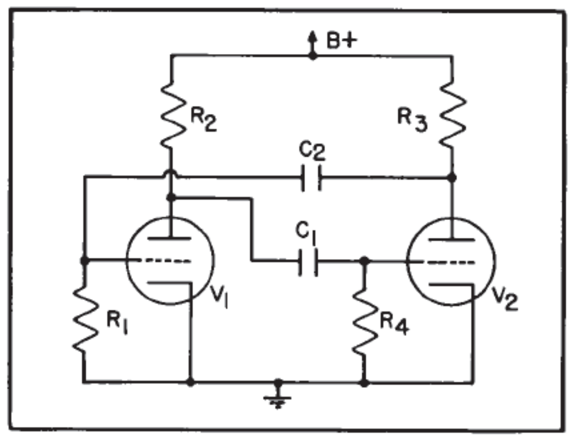

Figure 46-2 - Free-running multivibrator.

In Chapter 45 it was explained that a square wave is composed of a fundamental frequency and a large number of odd harmonics. Notice, that, due to the use of two consecutive amplifier stages, the square wave frequencies at the plate of V_2 are in phase with the signal at the grid of V_1. When the circuit is operated as a multivibrator, almost all of these frequencies present

A1. The feedback circuit in an LC oscillator is a resonant circuit, while the feedback circuit in a Wien Bridge oscillator is a non-resonant frequency selective bridge.

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at the plate of V_2 are coupled to the grid of V_1 by capacitor C_2.

By placing an RC filter network in series with C_2, all but one of these frequencies can be attenuated and the circuit becomes a sine wave oscillator. The schematic diagram of a basic Wien-bridge oscillator is shown in Figure 46-3.

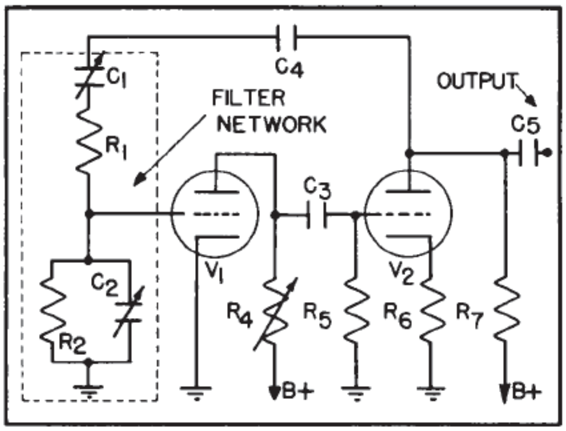

Figure 46-3 - Basic Wien-bridge oscillator.

The filter circuit which controls the output frequency consists of resistors R_1 and R_2, and capacitors C_1 and C_2. Mathematically f_{op} equals:

$$f_{op} = \frac{1}{2\pi\sqrt{R_1C_1\ R_2C_2}}$$

Normally $R_1 = R_2$ and $C_1 = C_2$. In this case the above equation reduces to:

$$f_{op} = \frac{1}{2\pi RC} \qquad (46\text{-}1)$$

where: f_{op} = the operating frequency in cps
R = the value of one of the equal resistors in ohms
C = the value of one of the equal capacitors in farads

If the resistors and capacitors in the filter network have values of 1000 ohms and 0.159 uf respectively, the operating frequency is computed as follows:

$$f_{op} = \frac{1}{2\pi RC} \qquad (46\text{-}1)$$

$$f_{op} = \frac{1}{(6.28)(1\times10^3)(1.59\times10^{-7})} = 1000 \text{ cps}$$

Thus, the output waveform would be a 1000 cycles per second sine wave.

Q2. What would happen to the output frequency of a Wien-bridge oscillator if the value of the frequency determining capacitors were decreased?

46-3. Feedback Circuit Analysis

The frequency of feedback voltage must also be 1 kc, and of a phase relationship equal to that of the output frequency. The amplitude and phase relationship of the grid input signal (the voltage across the parallel network composed of R_2 and C_2) may be computed by use of vector analysis. Figure 46-4 shows the filter network and the vector analysis. Assuming that the frequency fed back to the network will be 1 kc. It will be shown that at this frequency, the voltage felt at the grid of V_1 will be in phase with the feedback voltage.

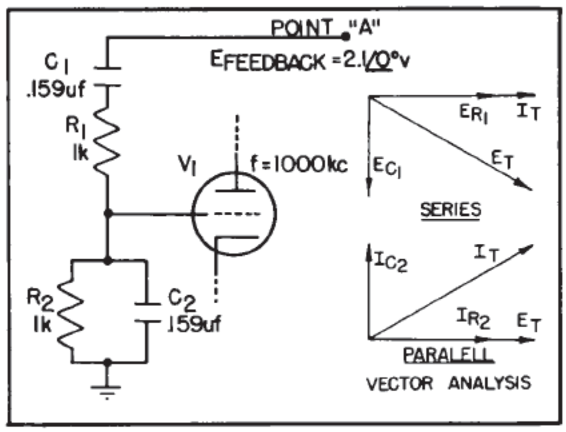

Figure 46-4 - Filter network.

The impedance between point A and ground will be:

$$Z_t = R_1 - jX_{C1} + \frac{R_2(-jX_{C2})}{R_2 + (-jX_{C2})}$$

The reactance of the capacitance at this frequency will be:

$$X_C = \frac{1}{2\pi f C}$$

Substituting values:

$$X_C = \frac{1}{6.28 \times 1 \times 10^3 \times 1.59 \times 10^{-7}}$$

$$X_C = 1000 \text{ ohms}$$

Therefore:

$$Z_t = 1000 - j\,1000 + \frac{(1000\angle 0^\circ)(1000\angle -90^\circ)}{1000 - j\,1000}$$

$$Z_t = 1414\angle -45^\circ + \frac{1 \times 10^6 \angle -90^\circ}{1414\angle -45^\circ}$$

$$Z_t = 1414\angle -45^\circ + 707\angle -45^\circ$$

$$Z_t = 2121\angle -45^\circ$$

If the feedback voltage is assumed to be $2.1\angle 0^\circ$ volts, the current at point A of this circuit will be:

$$I_t = \frac{E}{Z_t} = \frac{2.1\angle 0^\circ}{2121\angle -45^\circ}$$

$$I_t = 1\angle 45^\circ \text{ milliampere}$$

The voltage input to the grid of V_1 is the voltage across the parallel impedance of R_2 and C_2.

$$E_{in} = IZ_{R_2C_2}$$

$$E_{in} = I\,\frac{(R_2)(-j\,X_{C2})}{R_2 - j\,X_{C2}}$$

$$E_{in} = 0.001\angle 45^\circ \, \frac{(1000\angle 0^\circ)(1000\angle -90^\circ)}{1000 - j\,1000}$$

$$E_{in} = (0.001\angle 45^\circ)(707\angle -45^\circ)$$

$$E_{in} = 0.707\angle 0^\circ \text{ volts}$$

Since the output voltage is $2.1\angle 0^\circ$, and the grid input voltage is $0.707\angle 0^\circ$, they are in phase and oscillation at that frequency will occur. The difference between the output amplitude and the input amplitude is due to the attenuation of the filter network.

To show that only the 1 kc signal will be returned to the grid in phase with the output signal, two other frequencies will be fed back and their phase relationship to the output phase relationship will be compared. One of the test frequencies, 500 cps, will be below the operating frequency, and the other test frequency, 2 kc, will be above the operating frequency.

At 500 cps, the capacitive reactance will be:

$$X_C = \frac{1}{6.28(5 \times 10^2)(1.59 \times 10^{-7})}$$

$$X_C = 2000\angle -90^\circ \text{ ohms}$$

The total impedance of the network at this frequency will be:

$$Z_t = 1000\text{-}j2000 + \frac{(1000\angle 0^\circ)(2000\angle -90^\circ)}{1000 - j\,2000}$$

$$Z_t = 1000\text{-}j\,2000 + \frac{2 \times 10^6\angle -90^\circ}{2240\angle -63.5^\circ}$$

$$Z_t = 1000\text{-}j\,2000 + 893\angle -26.5^\circ$$

$$Z_t = 1000 - j\,2000 + 800 - j\,398$$

$$Z_t = 1800 - j\,2398$$

$$Z_t = 3000\angle -53^\circ$$

Assuming an output voltage of $2.1\angle 0^\circ$ volts, the current at point A with respect to ground is:

$$I_t = \frac{E}{Z_t} = \frac{2.1\angle 0^\circ}{3 \times 10^3\angle -53^\circ}$$

$$I_t = 0.7 \times 10^{-3}\angle 53^\circ \text{ amperes}$$

The input voltage taken across the parallel impedance of R_2 and C_2 is:

$$E_{in} = I_t\, Z_{R_2C_2}$$

$$E_{in} = (0.7 \times 10^{-3}\angle 53^\circ)(893\angle -26.5^\circ)$$

$$E_{in} = 0.625\angle 26.5^\circ \text{ volt}$$

Therefore, E_{in} is reduced to below the value of 0.707 volt and leads E_{out} at 500 cps by 26.5°. This phase relationship will not allow the circuit to oscillate.

The capacitive reactance at the test frequency of 2000 cps is:

A2. The output frequency would increase.

$$X_C = \frac{1}{6.28(2 \times 10^3)(0.159 \times 10^{-6})}$$

$$X_C = 500 \angle -90^\circ \text{ ohms}$$

The total impedance of the network from point A to ground is:

$$Z = 1000\text{-}j\,500 + \frac{(1000\angle 0^\circ)(500\angle -90^\circ)}{1000 - j\,500}$$

$$Z = 1000\text{-}j\,500 + \frac{5 \times 10^5 \angle 90^\circ}{1120 \angle -26.5^\circ}$$

$$Z = 1000\text{-}j\,500 + 446 \angle -63.5^\circ$$

$$Z = 1000\text{-}j\,500 + 198\text{-}j\,395$$

$$Z = 1198 - j\,895$$

$$Z = 1491 \angle -36.8 \text{ ohms}$$

Again assuming the output voltage to be $2.1\angle 0^\circ$ volts, the current at terminal A will be:

$$I_t = \frac{E}{Z_t} = \frac{2.1 \angle 0^\circ}{1491 \angle -36.5^\circ}$$

$$I_t = 1.408 \angle 36.5^\circ \text{ ma}$$

The input voltage, E_{in}, across the parallel network composed of R_2 and C_2 is:

$$E_{in} = I_t \, Z_{R_2C_2}$$

$$E_{in} = (1.408 \times 10^{-3} \angle 36.8^\circ)(446 \angle -63.5^\circ)$$

$$E_{in} = 0.627 \angle -26.7^\circ \text{ volt}$$

The output voltage is again below the 0.707 volt value, and the input voltage lags the output voltage by 26.7°. This circuit can not sustain oscillations at 2000 cps.

Q3. What is the frequency of a Wien-bridge oscillator with the values of R and C are 5 K and 0.5 uf respectively?

46.4. The Stable Wien-bridge Oscillator

Thus far, the only condition that satisfied the requirement for oscillation was with a feedback signal at 1000 cps. It was the only frequency which caused a voltage on the grid which is in phase with the output voltage. Also at the frequency of 1000 cps, the voltage fed back to the grid was at its highest value.

To make the Wien-bridge oscillator a very stable device another feedback path is introduced into the circuit. This feedback, instead of being regenerative, is degenerative. The degenerative feedback path is composed of resistor R_3 and the lamp, LP_1. The circuit thus constructed is known as a modified Wien-bridge oscillator. The additional feedback path is shown in Figure 46-5.

Two diagrams are shown. Figure 46-5A illustrates the bridge nature of the circuit, and Figure 46-5B is a simplified schematic showing variable regeneration.

Figure 46-5B illustrates why the additional

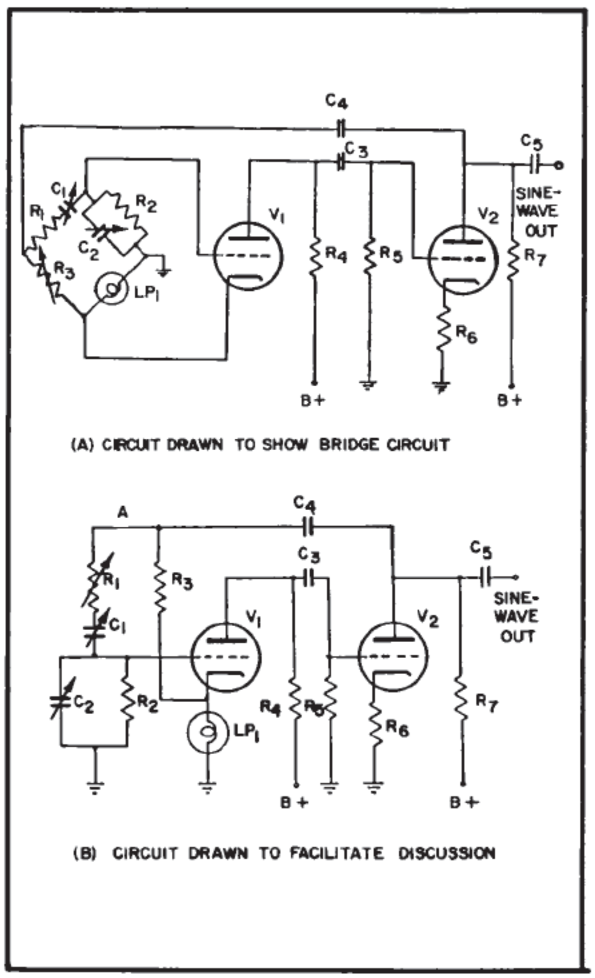

Figure 46-5 - Modified Wien-bridge oscillator.

feedback path is degenerative. The degenerative voltage is developed across the lamp, LP_1. The circuit is so designed that the value of the degenerative voltage is such that it will cancel the regenerative voltage applied to the grid with the exception of one frequency—the operating frequency.

As an example, if the value of degenerative voltage was as high as 0.7 volts, it would cancel the regenerative voltage fed to the grid at frequencies other than the correct operating frequency. At the operating frequency of 1000 cps, the value of regenerative voltage was 0.707 volts. The difference between the regenerative and degenerative voltage (0.707-0.700 = 0.007) is sufficient to cause the circuit to oscillate.

The resistor R_3 in the schematic of Figure 46-5B is made variable to control the amplitude of degeneration and is adjusted for purity of wave form.

A degenerative feedback voltage is provided by the voltage divider consisting of resistor R_3 and lamp LP_1. Since there is no phase shift across the voltage divider, and since the resistance is constant for all frequencies, the amplitude of the degenerative feedback voltage is constant for all frequencies which may present in the output of V_2. The degenerative or negative feedback voltage is plotted by curve (1) of Figure 46-6.

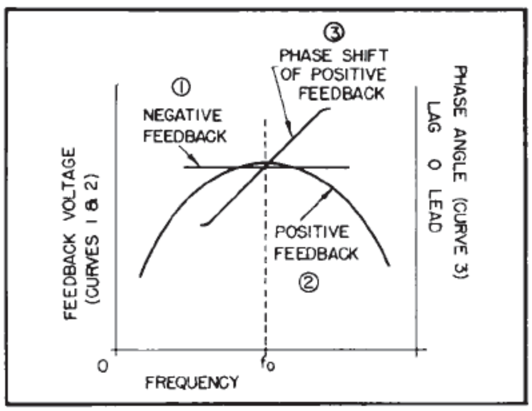

Figure 46-6 - Control effect of feedback.

The regenerative or positive feedback voltage is provided by the voltage divider network consisting of R_1, C_1, R_2 and C_2. The reactance of the capacitors is almost zero when the frequency is very high. In this case, resistor R_2 is shunted by a very low reactance making the voltage between the grid of V_1 and ground almost zero. On the other hand, if the frequency is reduced toward zero the current that can flow through either C_2 or R_2 is reduced to almost zero by the very high reactance of C_1. Therefore, the voltage between the grid of V_1 and ground falls almost to zero. However, at some intermediate frequency the positive feedback voltage is at maximum, as shown by curve (2) in Figure 46-6. The curve is rather flat in the vicinity of f_{op}, but the phase shift that occurs in the positive feedback circuit permits only a single frequency to be generated.

The voltage across R_2 is in phase with the output voltage of V_2 if R_1C_1 equals R_2C_2. If the frequency of the output of V_2 increases, the voltage across R_2 tends to lag the voltage at the plate of V_2. If the frequency decreases, the voltage across R_2 leads the output voltage of V_2. Curve (3) in Figure 46-6 shows the phase angle between these two voltages as the frequency of the feedback voltage is varied.

The purpose of the lamp (sometimes replaced by a thermistor) is to improve amplitude stability of the circuit.

When a small signal is applied to the grid, amplification occurs, and a large output signal is developed. As the output voltage increases, the value of the feedback voltage increases. As oscillations build up, the lamp resistance increases. The lamp filament is made of tungsten and its resistance increases with the temperature of the filament. If the value of the current through the tube increases the temperature of the lamp filament increases, the resistance of the lamp increases, (this is known as a positive coefficient of temperature) the value of degeneration increases maintaining the amplitude constant at the operating value.

Q4. A Wien-bridge type oscillator without the filter network is what type of circuit?

Q5. How may the frequency of the Wien-bridge oscillator be changed?

Q6. What is the purpose of the lamp in the Wien-bridge oscillator?

46-5. Phase Shift Oscillators

The PHASE SHIFT OSCILLATOR of Figure 46-7 consists of a single amplifier tube and a resistance-capacitance phase shifting feedback circuit. A standard phase shift oscillator requires that the signal fed back from the plate to the control grid be shifted 180° in order to sustain oscillations. This phase shift is necessary to reinforce the control action of the grid signal to make up for circuit losses. The phase shift is accomplished by three resistor-capacitor sections and operates identical to phase shift circuits described and illustrated in section 13-5. This resistor capacitor network not only

A3. $f_{op} \approx 64$ cps when utilizing $f_{op} = \frac{1}{2\pi RC}$

A4. A multivibrator.

A5. By varying the value of the ganged capacitors.

A6. To improve the amplitude stability of the circuit.

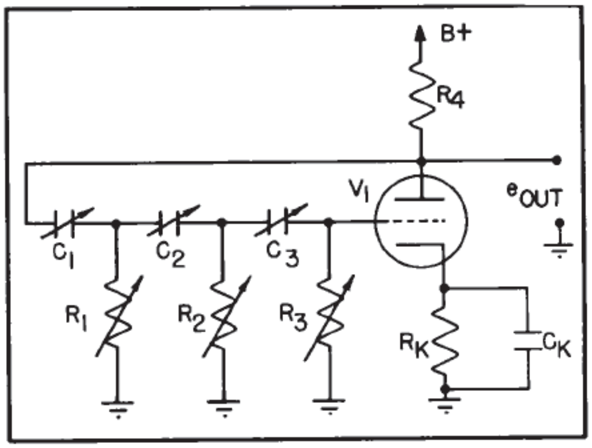

Figure 46-7 - Phase shift oscillator.

determines the frequency of oscillations but also performs the dual function of providing the proper phase and amplitude of feedback voltage.

The phase shift circuit illustrated in Figure 46-8 is known as a phase lead circuit. When an alternating voltage is applied to this circuit current flows in the circuit. Since the circuit impedance is capacitive, the current leads the voltage. The voltage drop E_R across resistor R is in phase with the current that flows through it. Therefore, the voltage E_R also leads the impressed voltage by the same phase angle.

When the resistor R is varied, the phase angle of the current in the circuit is also varied. If R were reduced to zero, the current (theoretically) would lead the applied voltage by 90°. However, adjusting R to zero would be impractical. First, because reducing R to zero would leave no impedance for developing an output voltage and secondly, with R equal to zero, the current would lead the applied voltage by less than 90° due to circuit losses. Therefore, a minimum of three sections in the phase shift circuit are required to produce the necessary

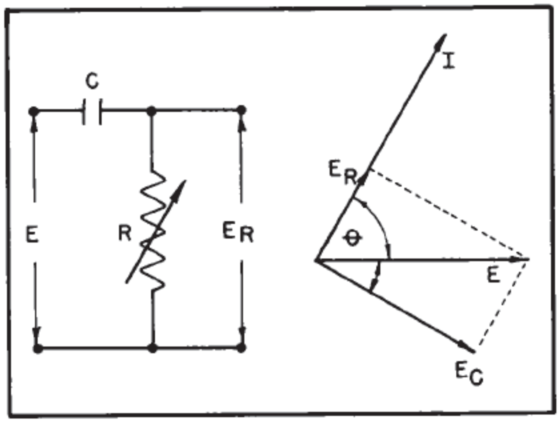

Figure 46-8 - Phase shift stage.

180° phase shift.

When the output of the first section is fed into the next section another phase shift is accomplished. When this output is fed into the third section, still another phase shift, where the current leads the applied voltage, occurs. Resistor R_3 is adjusted to make the output voltage 180° ahead of the voltage at the output of the amplifier tube. When the plate signal is shifted 180° and is applied to the control grid, the circuit will oscillate (Figure 46-7).

Since the resistance of resistors R_1, R_2 and R_3 (Figure 46-7) must be adjusted, the oscillator is usually employed where a fixed audio frequency is available.

Small frequency changes may be made by varying R_3 or C_3. If the frequency is to be decreased, either the resistance or the capacitance is increased. The oscillations in this circuit are started by any slight changes such as variations in the plate supply voltage or ordinary tube noises. Since noise is composed of all frequencies, one of them will be shifted 180° by the RC network, and oscillation at that frequency will begin.

The circuit shown in Figure 46-7 is controlled by an RC network known as a phase lead network. This is true because the voltage across the resistive component of an RC network always leads the voltage applied to the network. A circuit which uses a phase lag RC circuit to accomplish the 180° phase shift to produce oscillation is shown in Figure 46-9.

The phase shift oscillator is useful primarily in applications where a fixed frequency is desired.

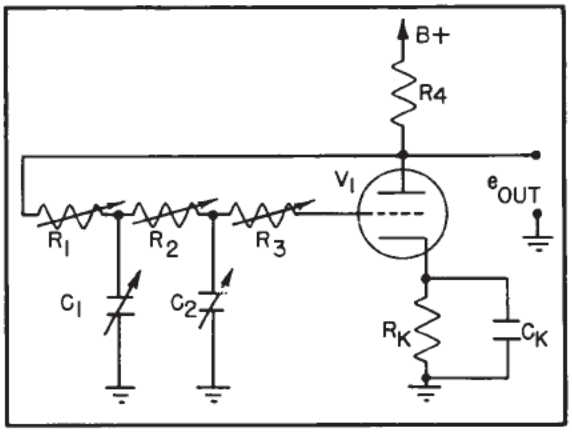

Figure 46-9 - Phase lag network.

EXERCISE 46

1. Compare the Wien-bridge oscillator to the free-running multivibrator.
2. What controls the frequency of the Wien-bridge oscillator?
3. What is the frequency of a Wien-bridge oscillator the RC values of which are 6K and 0.6 uf respectively?
4. Describe what controls the frequency stability of the Wien-bridge oscillator?
5. What is degeneration?
6. What types of feedback are used in the Wien-bridge oscillator?
7. If C_4 in Figure 46-4 were to open, what would happen?
8. What controls the amplitude of the frequency variations in the Wien-bridge oscillator?
9. What controls the frequency of the phase shift oscillator?
10. What starts the oscillation in the phase shift oscillator?
11. Why is a phase shift oscillator stable?

CHAPTER 47

BLOCKING OSCILLATORS

Oscillators presented in previous topics were of the sustained oscillation type; that is, once excited, the circuit produces continuous oscillations. In various pulse-operated circuits, such as those used in radar, a need exists for oscillators which produces periodic oscillations. Frequently, such oscillations are in the form of pulses of specific amplitude and shape recurring at a periodic rate.

One circuit which satisfies the requirements for producing periodic oscillations is the BLOCKING OSCILLATOR. A vacuum tube blocking oscillator can be defined as one which cuts itself off after one or more cycles due to the accumulation of a negative charge on the grid capacitor. Due to the effect of grid charge, the oscillations are interrupted or "blocked" intermittently. Blocking oscillators, by nature, are not stable to the extent that they may be used for precise timing, and must be synchronized by pulses from timing circuits.

Two general types of blocking oscillators exist, and are distinguished by the number of cycles produced before blocking action occurs. The SINGLE SWING type is one in which the tube is cut off after completing one cycle. The SELF-PULSING type is one which produces more than one cycle before the tube cuts off.

Another oscillator which satisfies the requirements of pulse-operated circuits is the RINGING OSCILLATOR. Basically, this oscillator operates on the principle of producing highly damped oscillations from a shock-excited tank circuit. Although its operation does not qualify it to be called a blocking oscillator, it does provide a simple method of producing periodic oscillations.

In this chapter, the operation and application of the RINGING OSCILLATOR, SELF-PULSING BLOCKING OSCILLATOR, SINGLE-SWING BLOCKING OSCILLATOR, and DRIVEN BLOCKING OSCILLATOR, will be considered.

The importance in understanding the operation of the blocking oscillators lies in the fact that they are used extensively where the generation of specialized waveshapes is required. Since they are frequently employed in military electronic equipments, their operation should be well understood by the electronics technician.

RINGING OSCILLATOR

47-1. Principles of Operation

When a tank circuit is shock excited, circulating currents within the tank occur. Such action is termed the flywheel effect. It is produced by the action of the capacitance and inductance which form the tank circuit. It will be recalled that the losses in a practical tank circuit cause succeeding cycles of oscillating current to diminish in amplitude, so that a damped wave is produced across such a tank. If such losses are not continuously replaced (proper feedback), sustained oscillations will not occur.

The basic operating principle of the ringing oscillator is shown in Figure 47-1, where switch S_1 is shown connected in series with a tank circuit, a current limiting resistor, and a 150 volt source. The potential difference appearing across the tank is shown by the accompanying waveform. The generation of such a waveform will now be considered.

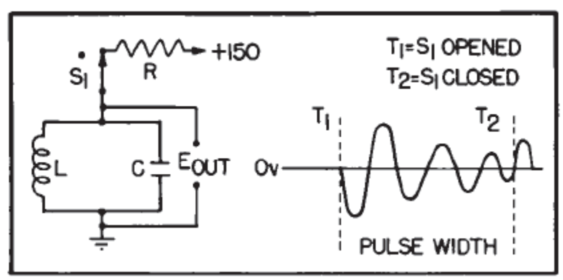

Figure 47-1 - Manually operated ringing oscillator.

Assume S_1 (Figure 47-1) is initially closed. A large current flows through the low resistance of L, which prevents any tank oscillations. For practical purposes, the voltage across the tank is zero (L is, effectively, a short circuit). The large inductive current produces a field about the coil which remains stationary, so long as S_1 remains closed.

At time T_1, S_1 is opened and the inductive field collapses causing current to continue flowing up through the coil. This current charges C_1 so that its potential (and that of the tank) is negative to positive, top to bottom. This estab-

lishes shock oscillations with a resultant waveform in Figure 47-1. As time passes, the oscillating current produces successively smaller capacitor charges. However, the Q of the tank is quite high and oscillations would persist for many cycles.

Assume at time T_2, S_1 is again closed. This causes a large current to flow through L, effectively shorting C_1 and causes tank oscillations to cease. The counter EMF produced in the coil by this sudden rush of current will develop a positive-to-negative (top to bottom) potential across the tank, as shown by the waveform. In conclusion, therefore, it can be said that opening of the switch in Figure 47-1 will develop output oscillations while closing of the switch will cause oscillations to cease.

The frequency of oscillations in the tank is determined by the values of inductance and capacitance in the tank circuit. The series of oscillations produced each time the switch opens can be considered to be a pulse. The rate at which the switch is opened and closed determines the PULSE REPETITION FREQUENCY (PRF). The duration of such a pulse (or pulse width) is determined by the time lapse between the opening and closing of the switch. The maximum pulse width is the time for natural damping to diminish the output to a prescribed level.

The value of series resistor, R, determines the amount of coil current flowing (and the resultant magnetic field) when S_1 is closed. If R is quite small, coil current will be large with a correspondingly large magnetic field around the coil. If R is large, coil current is small as is the associated magnetic field. The pulse amplitude produced when the switch opens is a function of the energy stored in the coil's magnetic field; so that, with a large field the voltage across the tank will be large when oscillations are produced. It follows, also that the larger the initial tank voltage fluctuations, the longer such fluctuations will be sustained before natural damping reduces them to a prescribed amplitude.

Although the manual method of providing ringing oscillations enables simple analysis of the principles involved, such a circuit would be of limited practical use. Through the use of an electronically controlled switch, such as the vacuum tube, a more practical circuit can be constructed. Such a circuit will be considered in the following topic.

Q1. Why is the first alternation of the output signal in Figure 47-1 always negative?

Q2. What determines the frequency of oscillations?

Q3. When does the tank begin to oscillate?

47-2. Vacuum Tube Ringing Oscillator (Quiescent)

In the manually operated ringing oscillator described in the previous topic, manual operation of the switch greatly limited the number of pulses (FRF) which may be generated in a given unit of time. There would also be problems in trying to maintain a given pulse width with any degree of accuracy. Through the use of an electronically controlled switch, the problems of speed and accuracy are easily solved.

Figure 47-2 shows a basic ringing oscillator in which the vacuum tube provides the necessary switching action. This switching action is controlled by the application of gating pulses to the input circuit.

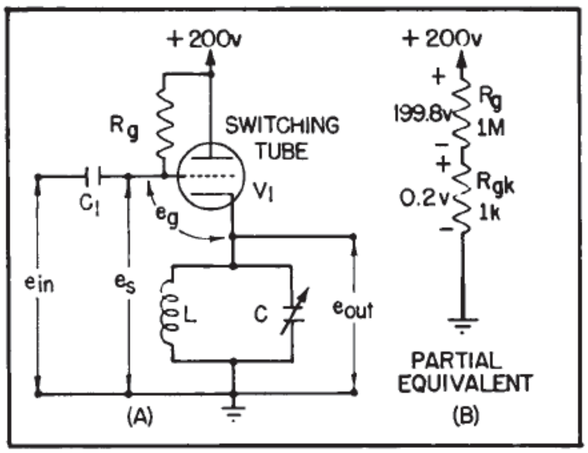

Figure 47-2 - Basic ringing oscillator.

In the basic ringing oscillator shown in Figure 47-2, the grid is returned to B+ through a large resistor R_g. As a result, the tube is normally conducting and grid current flows. The actual point of tube operation is determined by the relative values of R_g and the cathode-to-grid resistance of the tube (R_{gk}). The voltage divider formed by R_g and R_{gk} can be better visualized by referring to the partial diagram in Figure 47-2B. As grid current flows from cathode through R_{gk} and R_g to +200 volts, the large value of R_g drops practically the entire supply voltage leaving the grid positive by approximately 0.2 volt. The total current drawn by the tube flows through the tank inductor, L, creating a large steady magnetic field. Neglecting the small resistance of L, the output across the tank can be considered as being zero volts. In the quiescent condition, therefore, V_1 acts as a closed switch providing large tank coil current which prevents tank oscillations.

When a negative signal is applied to the input of the circuit, the conditions of the circuit are converted from a quiescent state to a dynamic state. Circuit operation under dynamic conditions will be considered in the following topic.

Q4. In the ringing or shock-excited oscillator, what is the function of the tube?

Q5. During quiescence what is the status of the vacuum tube in a ringing oscillator?

Q6. What is the status of the tank circuit during quiescence?

47-3. Vacuum Tube Ringing Oscillator (Dynamic)

Operation of the switching tube used in a ringing circuit is usually controlled by a large negative square wave or "gate pulse" applied to the grid. If the signal is of sufficient magnitude the tube will cut off. Under this condition, the tube acts as an open switch, interrupting the large direct current flowing through the tank coil. As a result, tank oscillations will occur in the same manner as described in section 47-1.

Normally, it is desired to produce a specific number of oscillations during the time the negative gate is applied to the tube. By knowing the time duration of the gating pulse and the number of tank oscillations required, the tank circuit resonant frequency can be determined, since:

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{T_t}$$

For example, assume the gating pulse is 1000 microseconds long and 4 cycles of oscillation are required from the tank. The period of one cycle would be:

$$\frac{1000 \text{ u sec}}{4} = 250 \text{ microseconds}$$

Converting period to frequency gives:

$$f_o = \frac{1}{T_t} = \frac{1}{250 \text{ u sec}} = 4,000 \text{ cps}$$

Consequently, the desired tank resonant frequency would be 4 kc to provide 4 oscillations during the application of a 1000 microsecond gating pulse. This is shown in Figure 47-3.

Since the tube acts as a switch, the tank frequency is unaffected by changes in tube characteristics. In applications where extreme stability is required, the tank circuit is placed in a temperature-controlled environment, such as an oven, to prevent temperature changes affecting tank frequency.

The circuit of Figure 47-3 shows the ringing oscillator during the time that the tube is cut off by a negative gating pulse. It also shows a time

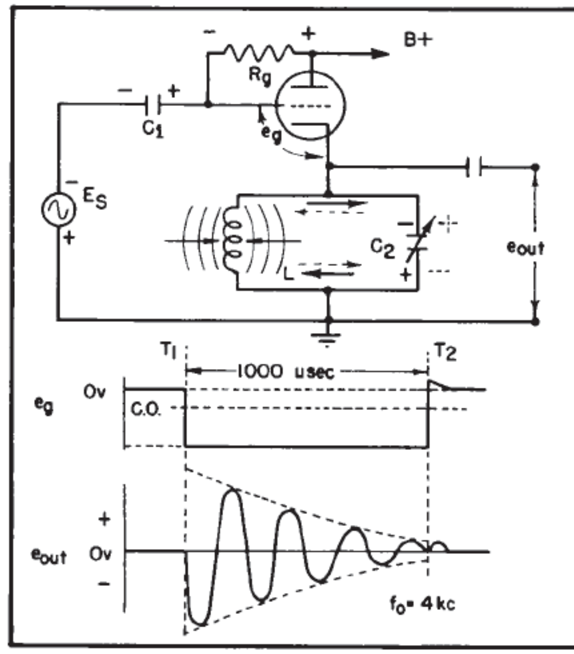

Figure 47-3 - Ringing oscillator with negative voltage applied.

comparison between the gating pulse and the output waveform. At the instant the negative gate voltage is applied (T_1), the tube cuts off, and the field around L collapses tending to keep current flowing up through L. This current charges C_2 and produces the initial negative output alternation. The tank resonant frequency (f_o) is 4 kc, so that during the time the 1000 microsecond gating pulse is applied, four cycles are produced in the output.

As oscillations continue, the tank circuit losses produce a damped output waveform. If the tube is cut off for a sufficiently long period of time, the oscillations would completely damp out. To insure that oscillations continue during entire length of the gating pulse, the tank circuit must have a high Q (high X_L to R ratio). This keeps the tank circuit losses low and provides minimum damping.

Referring to the output waveform of Figure 47-3, a positive damped alternation is shown at T_2. This occurs at the end of the gating pulse and is due to the sudden conduction of tube current through the tank coil, producing a counter EMF. The amplitude of this positive alternation is small because the low plate resistance of the conducting tube shunts the tank circuit. This is the same effect encountered in cathode followers where the plate resistance shunts the cathode resistor.

A1. Because, at the instant S_1 is opened, the collapsing field about the tank coil keeps current flowing up through it, charging C_1 negative on the top to positive on the bottom.

A2. The inductance and capacitance values forming the tank circuit.

A3. Each time the switch is opened.

A4. It functions as a switch controlling the direct current flowing through the tank coil.

A5. Grid current flows through the voltage divider composed of R_g and the cathode-to-grid resistance. This develops a slight positive potential on the grid causing a large amount of plate current.

A6. The large tube current flowing through the tank coil develops a large magnetic field around the coil. The small coil resistance effectively shorts the tank capacitor with the result that no oscillations exist.

During the portion of oscillations in which the output waveform is negative, the switching tube cathode becomes negative with respect to ground as shown in Figure 47-4. This produces a potential difference between cathode and plate which is greater than B+(230 volts). A negative gating pulse of sufficient magnitude must be applied to the grid to prevent the possibility of premature tube conduction during the negative alternation of the tank circuit voltage.

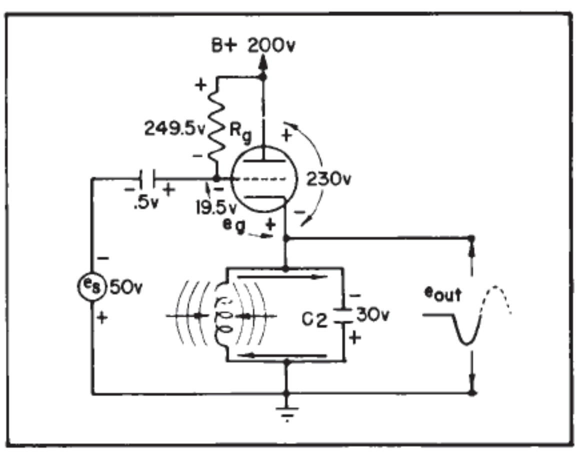

Figure 47-4 - Ringing oscillator circuit conditions during negative alternation of output voltage.

The negative cathode potential also reduces E_{gk} by subtracting from the negative gating pulse (E_g - E_k = 49.5 - 30 = 19.5 V) which effectively reduces the bias and tends to cause the tube to go into conduction. Thus, the negative gating pulse MUST BE LARGE ENOUGH to keep the tube cut off when the output alternations reach their maximum negative value.

By way of summary, it can be said that the ringing oscillator is not free running. Its output frequency is determined by tank inductance and capacitance. The number of oscillations in the output signal is determined by the tank circuit resonant frequency and the duration of the gating pulse. The pulse rate is determined by the gating pulse frequency, and oscillations occur when the switching tube is cut off. The tank circuit should have a high Q to prevent excessive damping action. The tube acts as a switch between the tank and the dc source. Since oscillations are not interrupted by a negative charge on the grid capacitor, the ringing or shock-excited oscillator is NOT a blocking oscillator by definition.

Ringing oscillators find application where oscillations of a certain frequency and time duration are required periodically.

Q7. If a gating pulse of 5000 microseconds was used and 10 cycles of oscillation in the output were desired, what would be the required tank resonant frequency?

Q8. Of what polarity is the first output alternation from a ringing oscillator?

Q9. Why are high Q tank circuits desirable?

Q10. What effect does the negative alternation of the tank output signal have on the tube bias?

Q11. When will the tank circuit oscillate?

Q12. What determines the period of time in which oscillations occur?

Q13. During a given input gating pulse, how should tank capacitance be varied to provide a greater number of oscillations?

SELF-PULSING BLOCKING OSCILLATORS

47-4. General Operation

The self-pulsing blocking oscillator provides output oscillations for more than one cycle before blocking action occurs. If certain modifications are made to the basic Hartley oscillator, self-pulsing action will occur. To understand the

manner in which self-pulsing action will occur, the method of producing grid leak bias should first be understood. Figure 47-5 shows a Hartley during the period of tank oscillations when grid current flows.

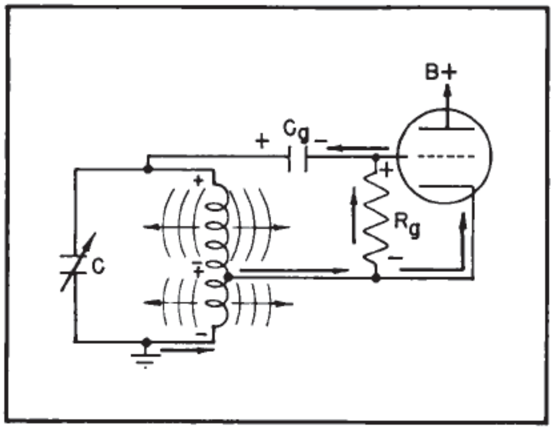

Figure 47-5 - Grid capacitor charge in a Hartley oscillator.

In Figure 47-5, C_g is shown charging quickly through the relatively low cathode-to-grid tube resistance during the period of time that the top of the tank circuit is positive. Since R_g is large, the capacitor charging current flowing through this resistor is small.

When the top of the tank circuit becomes negative, as shown in Figure 47-6, C_g begins discharging. Its discharge path is through R_g resulting in a long time constant (R_g C_g). The value of R_g is such as to permit a given amount of discharge from C_g during the negative alternation of tank voltage. The average capacitor charge is proportional to the RF voltage across the tank so that as the amplitude of the tank oscillations increases, grid leak bias increases and tends to maintain a constant amplitude across the tank.

If the value of R_g, in Figure 47-6, is sufficiently large, a very small amount of capacitor charge would leak off during the period the tank voltage is negative. On succeeding positive alternation, the charge on C_g will increase. A point would be reached where the discharge current would prevent tube conduction during the positive alternation of tank voltage. Without tube conduction, the losses within the tank circuit are not replaced. As a result, tank oscillations will become damped and eventually cease.

Tank oscillations will not recur until C_g has discharged sufficiently to allow the tube to conduct, energy is supplied to the tank circuit and oscillations begin. Again, after several cycles of oscillation, the grid capacitor is sufficiently charged to prevent tube conduction and oscillations soon cease. Thus, the operation of the

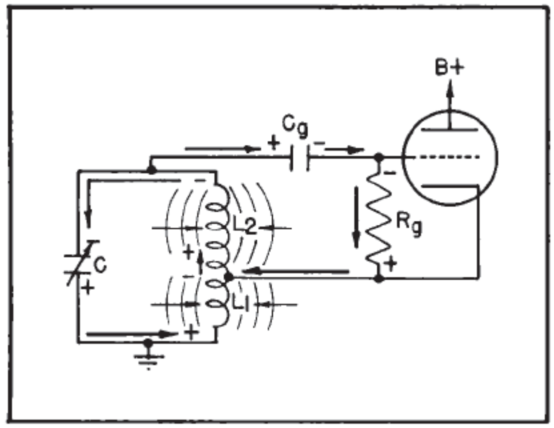

Figure 47-6 - Grid capacitor discharge in Hartley oscillator.

oscillator is intermittent and is said to be self-pulsing.

Q14. What change is made to the basic Hartley oscillator to make it self-pulsing?

47-5. Detailed Operation

The detailed operation of the self-pulsing oscillator will begin with application of B+ to the circuit of Figure 47-7. Initially, current increases through L_1, developing an expanding field that cuts the windings of L_2. Counter EMF produced in the tank coils produces a positive potential at the top of L_2. This positive potential is applied to the grid causing increased tube conduction and grid current flow. Increased tube conduction through L_1 develops a greater field and provides for more positive tank potential. This regenerative action continues as long as current through L_1 changes. Maximum positive potential will be developed at the instant tube

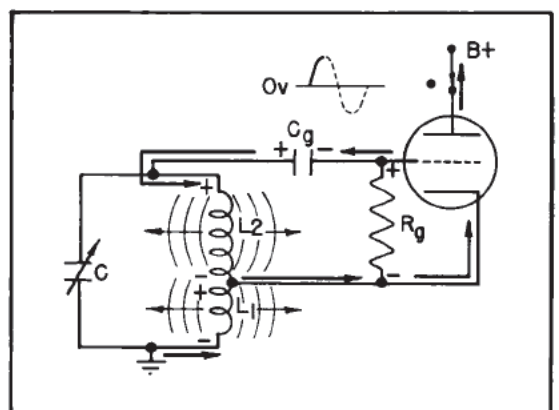

Figure 47-7 - Positive alternation of tank voltage in self-pulsing oscillator.

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A7. 2 kc.

A8. Negative.

A9. To reduce the damping effect in the tuned circuit.

A10. It decreases the bias.

A11. When the tube is cut off by the input negative gating pulse.

A12. The time duration of the input negative gating pulse.

A13. Tank capacitance should be reduced.

A14. Increase the R_g-C_g time constant so that discharge current keeps the tube cut off for a period greater than one cycle of tank oscillation.

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current is increasing at its greatest rate. This causes the field about L_1 to expand at maximum rate.

It should be noted that the positive grid potential causes grid current to charge C_g. Since the charge path has a relatively short time constant, the capacitor will charge almost as fast as the positive tank voltage is increasing.

Figure 47-8 shows the entire grid-to-cathode waveform (the sum of tank voltage and e_{cg}) along with e_{cg} by itself. Notice during the positive alternation that the voltage across C_g subtracts from the tank voltage so that the positive potential applied to the grid is the difference between the two.

Figure 47-9 shows the circuit conditions at the instant plate current no longer increases. At this time, C_g is charged to the tank potential and the resultant grid voltage is zero.

Due to the steady tube current flowing through L_1, the field no longer expands and the tank potentail decreases. This, in turn, causes C_g to begin discharging through R_g and the grid potential goes negative. As a result, plate current decreases as shown in Figure 47-10A.

With a decrease in plate current, the field about L_1 and L_2 begins to collapse, keeping current flowing up through the coils and charging the tank capacitor. The negative potential at the top of the tank adds to the charge of C_g so that their sum is applied across R_g. This drives the tube into cutoff as shown in Figure 47-10B.

As the potential across the tank goes through the negative alternation, C_g attempts to discharge through R_g. As is shown in Figure 47-8, C_g can discharge only slightly, since R_g C_g is quite long.

When tank potential starts positive, its voltage will add less to the charge of C_g so that grid potential will become less negative. This is shown by the circuit of Figure 47-11 and the waveform of Figure 47-8.

As the grid potential becomes less negative, a point is reached where the tube will begin to

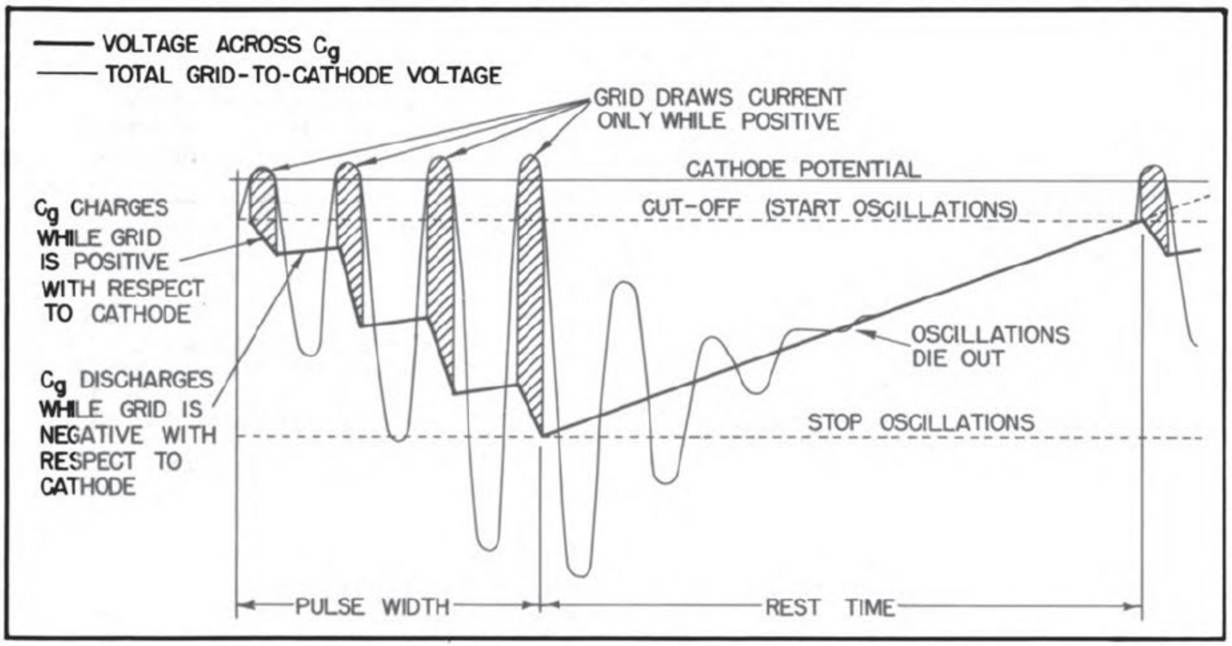

Figure 47-8 - Self-pulsing blocking oscillator, E_g and E_{cg}.

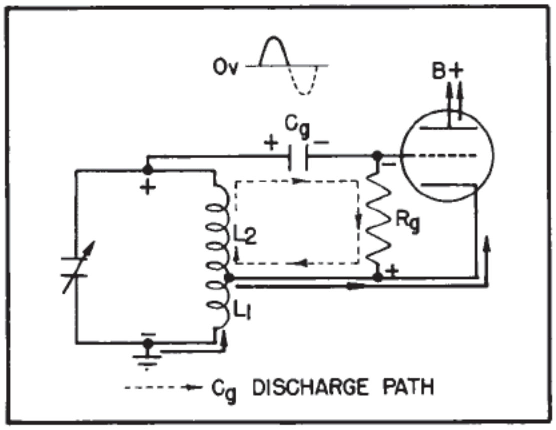

Figure 47-9 - Self-pulsing blocking oscillator when tube current stops increasing.

conduct. Tube current through L_1 will aid the positive change in tank potential. This, in turn, will further reduce the negative grid potential, causing tube conduction to increase. At some point the grid potential will become positive as shown by the waveform in Figure 47-8. At this time, C_g will take on additional charge due to grid current flow.

The cycle of operation just analyzed will repeat itself with C_g charging to a higher potential during the period grid current flows. However, the charge accumulated during the charge period greatly exceeds the charge removed during the discharge period, so that eventually the discharge current of C_g through R_g will cut off the tube for more than a complete cycle. As can be seen in Figure 47-8, when the tank voltage goes positive on the fifth cycle, there is insufficient tank voltage to bring the tube out of cut off, due to the large potential across C_g. As a result, oscillations damp out quickly and C_g continues to slowly discharge. At some point, the potential across R_g due to capacitor discharge will be insufficient to maintain cut off, and a new series of oscillations will begin. Figure 47-12 shows time variations of E_{cg} and the output from this circuit, which is inductively or capacitively coupled from the tank.

The period of time during which oscillations of a given amplitude occur is known as the pulse width of the output waveform. This width is determined primarily by the capacitance of C_g. If C_g is large, it will require more cycles to charge to a value sufficiently great to maintain tube cut off. Thus, as seen in Figure 47-12, more cycles will occur if Cg is increased. This, in turn, increases the output pulse width.

The time between series of oscillations is known as the REST TIME (or pulse interval), and is determined by the time constant of R_g and C_g. This time constant is normally controlled by varying the value of R_g. If R_g is increased, the discharge time becomes longer, requiring more time for C_g to discharge to cut off potential. This increases the rest time.

Two frequencies are involved in the output of a self-pulsing blocking oscillator. These consist of the oscillation frequency, determined by the values of inductance and capacitance forming the tank, and the number of oscillation groups or pulses per second, called the pulse repetition (or RECURRENCE) frequency (PRF). The PRF is controlled by varying the R_g C_g time constant. If the time constant is long, the rest time is also long and fewer pulses will be produced per second (lower PRF). If the rest time is decreased, the PRF increases.

By way of review, the Hartley oscillator can be modified to operate as a self-pulsing blocking oscillator if the value of R_g is increased. This decreases the discharge capability of C_g during the negative alternation of tank potential. The tube normally conducts on each positive

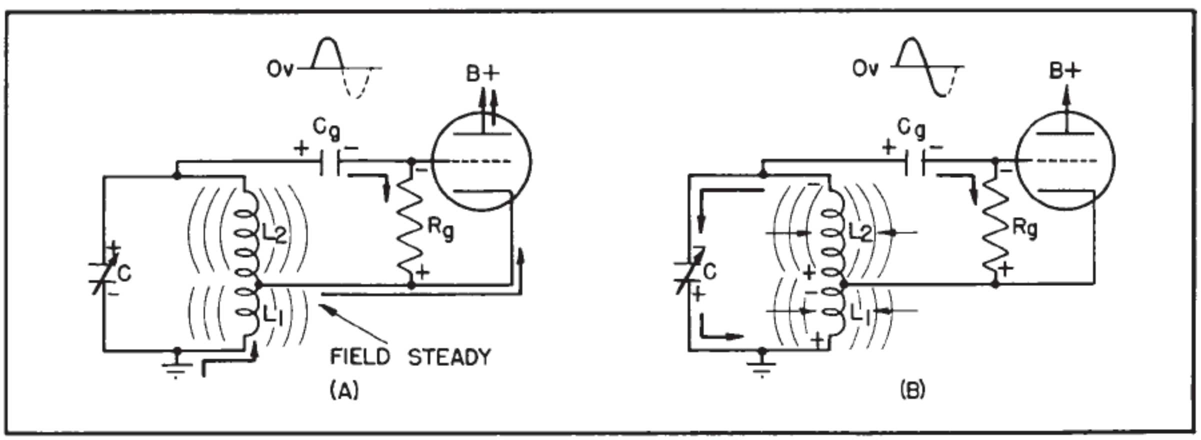

Figure 47-10 - Self-pulsing blocking oscillator as grid potential goes increasingly negative.

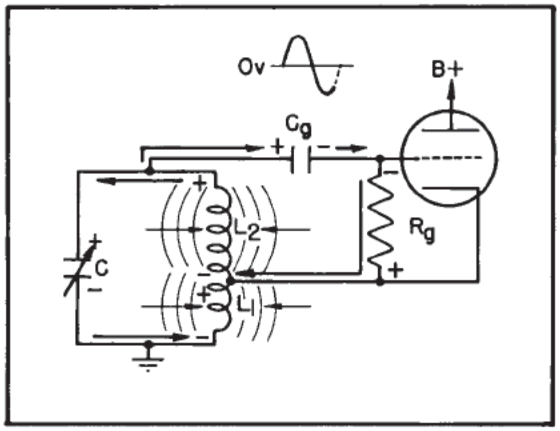

Figure 47-11 - Self-pulsing blocking oscillator as grid potential becomes less negative.

alternation and replaces tank circuit losses to sustain oscillations, due to regenerative feedback. As oscillations continue, the charge on the grid capacitor increases until sufficient charge is accumulated to cut off the tube for even the most positive tank potential. The output pulse width is controlled mainly by the value of C_g while the rest time is controlled by the R_g C_g time constant.

Q15. When is e_g at its maximum positive value?

Q16. Describe the operation of C_g when tube current is increasing.

Q17. At the instant tube current reaches its maximum value and becomes steady, what causes it to decrease?

Q18. What happens to C_g during the time the tube is cut-off?

Q19. How is pulse width affected if C_g is increased? Why?

Q20. How is PRF affected if the value of R_g is increased?

Q21. If C_g were to decrease in value, what would happen to PRF? To pulse width? To rest time?

SINGLE SWING BLOCKING OSCILLATOR

47-6. Free-Running

In contrast to the self-pulsing blocking oscillator, which produces several oscillations before blocking action occurs, the single swing blocking oscillator produces one cycle for each output pulse. One alternation of this output is normally much larger in amplitude than the other, and is usually used for the generation of synchronizing pulses. This output pulse or "spike" as it is commonly called, is very narrow; usually from 0.05 to 25 microseconds in duration. Normally the PRF is in the audio frequency spectrum.

Two types of single swing blocking oscil-

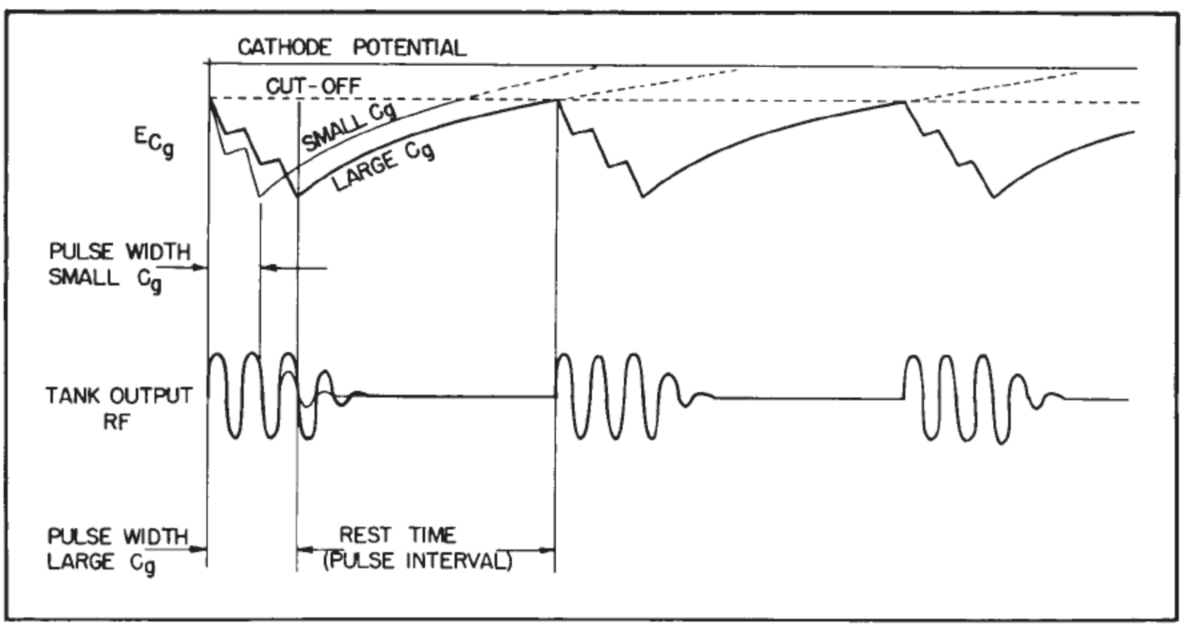

Figure 47-12 - RF output and E_{cg} of a self-pulsing blocking oscillator.

lators are most frequently used. The first to be discussed is the free-running type which is shown in Figure 47-13. The circuit consists of a vacuum tube, pulse transformer, grid resistor, and grid capacitor.

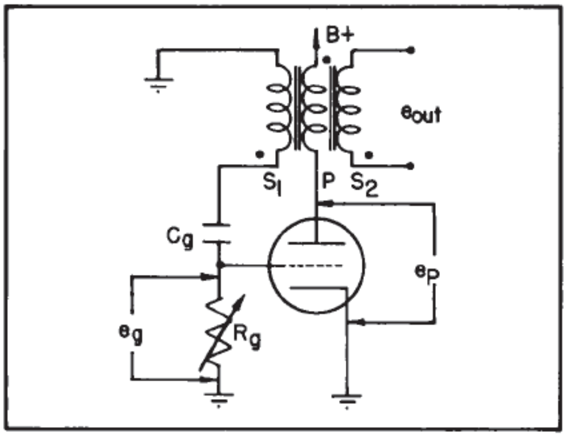

Figure 47-13 - Basic free-running blocking oscillator.

A pulse transformer, as used in the circuit of Figure 47-13, consists of a primary (P), a secondary winding (S_1) and a tertiary winding (S_2). Pulse transformers are specially designed for use in pulse circuits where an ordinary transformer would round-off or otherwise distort the output pulse. As will be explained shortly, the pulse transformer controls the rise and fall of plate current and aids in determining the output pulse width. The dots associated with the transformer in Figure 47-13 are called "polarity dots" and indicate the terminals which have the same instantaneous polarity. Note that the dots used in the pulse transformer indicate phase of the winding. The normal turns ratio of a pulse transformer (P to S_1) is on the order of unity.

To analyze the oparation of the free-running blocking oscillator, the waveforms of Figure 47-14 will be used.

At the instant B+ is applied to the circuit (T_0 in Figure 47-14), tube current flows as shown in Figure 47-15. This current flows through the pulse transformer primary winding causing an expanding magnetic field to be set up around this winding. This expanding primary field induces voltages in the secondary and tertiary windings in such a manner that e_g goes positive while e_{out} goes negative.

Induced voltage in the secondary and tertiary windings cause current flow which will then induce a counter EMF in the primary. This counter EMF in the primary will aid in reducing plate voltage. The speed of buildup of the primary magnetic field will then determine through transformer action the speed of reduction in part

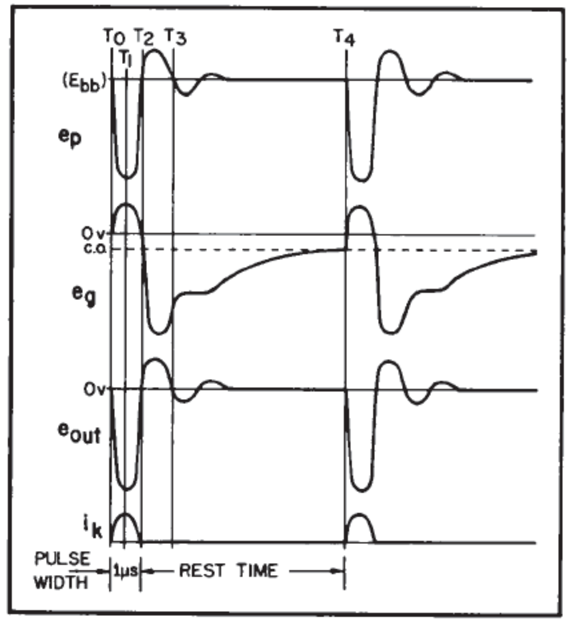

Figure 47-14 - Waveforms of a free-running single swing blocking oscillator.

by this counter EMF.

This positive signal induced in S_1 is coupled by C_g to the grid of the tube to increase tube current; which in turn provides more positive grid potential. In a very short period of time, e_{out} drops rapidly and e_g rises sharply as indicated by the waveforms of 47-14. Since the grid is positive, grid current charges C_g rapidly to the positive potential induced in S_1.

At time T_1, e_p has decreased and e_g has increased to a point where plate current will no longer increase. Time T_1 is then the point of maximum grid voltage and minimum plate voltage. At this point there is no change in plate

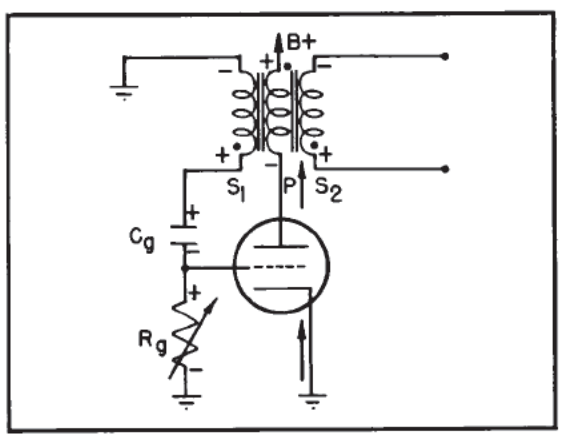

Figure 47-15 - Free-running blocking oscillator operation when tube current increases.

A15. When current through the tank inductance is increasing at its fastest rate, thereby producing maximum positive voltage across the tank.

A16. C_g charges rapidly because of grid current.

A17. When plate current becomes steady, no voltage is induced in L_2, causing C_g to discharge through R_g. This produces a negative grid voltage, lowering the conduction of the tube.

A18. Discharges at a slow rate.

A19. The pulse width increases because C_g charges more slowly, requiring a greater number of cycles before the capacitor charge is sufficiently great to cut off tube conduction on the positive peaks of tank voltage.

A20. PRF decreases.

A21. PRF would increase and pulse width would decrease. Rest time would decrease.

---

current and therefore the field around the plate winding ceases to increase.

With the field around the primary stationary there is no voltage induced in the secondary winding. The absence of induced voltage in S_1 causes C_g to begin to discharge down through R_g, developing a high negative grid voltage which drives the tube from high conduction to cutoff at a very rapid rate. This rapid change in tube conduction is caused by a combination of C_g discharging and the collapsing field about the transformer primary. As the primary field collapses, a negative potential is induced in S_1 causing the grid to become more and more negative. This action is shown in Figure 47-16, and the waveforms of Figure 47-14 times T_1 to T_2. This action continues until the grid is driven well beyond cutoff, thus completing a cycle of operation.

Note that between times T_2 and T_3, the plate voltage swings positive above the value of B+. This is due to the small inductance (inductive kick) in the pulse transformer. This field collapses rapidly and the voltages induced in S_1 and S_2 soon disappear, as shown at T_3 in Figure 47-14.

Oscillation does not start again immediately, however, because the charge on C_g must leak off through R_g.

After T_3, small oscillations appear in the waveforms of e_p, e_{out}, and e_g. These are shock-

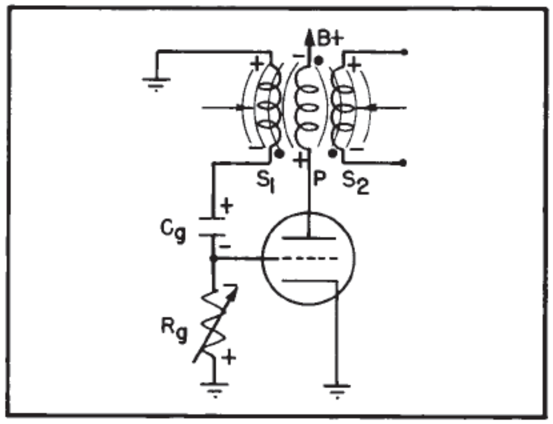

Figure 47-16 - Effects of collapsing primary field.

excited oscillations produced by the inductance resonating with stray capacitance as a result of the sudden transformer primary field collaps. These oscillations are undesirable and should be minimized. The most common method of reducing these unwanted oscillations is by placing a resistor in parallel with the secondary winding S_1 producing high damping.

From times T_3 to T_4 in Figure 47-14, the tube remains cut-off and C_g discharges slowly through the large resistor R_g. The length of time required for C_g to discharge before the tube conducts is determined by the R_g-C_g time constant. This time constant is usually controlled by varying the value of R_g. Since the time from T_3 to T_4 is the rest time, it can be said that R_g controls the rest time and can be used to change the PRF.

Primarily the time consumed by the rise and decay of plate current is determined by the inductance and resistance of the pulse transformer. This time determines the pulse width. The time of the rise in plate current will be controlled to a small extent by the charge time of C_g. Therefore, if the pulse transformer inductance is small, the field will build up and decay rapidly ($T_c = L/R$) also, if the value of C_g is small the charge time of this capacitor will be short allowing the tube to reach maximum conduction rapidly.

Several methods are available for obtaining the output from a free-running blocking oscillator. One method, as already seen, is the use of a tertiary winding on the pulse transformer. A second method would be to capacitively couple the output from the plate of the tube. This method of coupling has disadvantages due to the frequency range of this type of blocking oscillator with regards to pulse width and PRF. A third method is to place a small unbypassed resistor in the cathode circuit. The voltage

produced across such a resistor would be positive during conduction as shown by the waveform, i_k, in Figure 47-14.

By comparing waveforms in Figure 47-14, it can be seen that the output taken from the tertiary winding (e_{out}) is rounded more at the peak than e_p. This is due to the lag in field build-up in the tertiary winding. The number of pulses or spikes per second from the oscillator is its PRF. Pulse transformers are usually fixed components, therefore, the variable with regards to PRF is R_g which also varies the rest time. Therefore, PRF is inversely proportional to the R_g C_g time constant or the rest time.

In summary, the free-running single-swing blocking oscillator produces sharp pulses or spikes the width of which is primarily determined by rise and decay of the magnetic field around the primary winding of the pulse transformer. The factor determining this time (pulse width) is transformer inductance. The polarity dots of the pulse transformer indicate the points which have the same instantaneous polarity. To provide high damping action, the pulse transformer is constructed to minimize stray capacitance and has high winding resistance. Although efficiency is sacrificed, the primary objective in the design of a pulse transformer is the production of sharp pulses which may be used for synchronizing or triggering purposes.

Outputs can be taken by means of a tertiary transformer winding, by capacitive coupling from the plate circuit or through the use of an unbypassed cathode resistor. One desirable feature of the tertiary winding is that either output polarity is available simply by reversing the output terminals.

Although the ability of the oscillator to operate without the need for input signal has its applications, in some cases it is desirable to trigger or synchronize the operation of the single-swing blocking oscillator. Such a synchronizing oscillator will be considered in the following topic.

Q22. Why does grid voltage go positive in the free-running blocking oscillator as tube current increases?

Q23. When does plate voltage become minimum and grid voltage become maximum positive?

Q24. What determines pulse width?

Q25. What causes the rapid decrease in tube current after maximum steady conduction is reached?

Q26. What causes plate voltage to go above B+?

Q27. What happens to rest time if R_g is decreased?

Q28. Why is a resistor added in parallel with the pulse transformer output?

47-7. Synchronized Blocking Oscillator

The free-running blocking oscillator studied in topic 47-6 is relatively unstable. Its PRF is determined by the discharge time constant of C_g through R_g. Figure 47-17 shows the effect of slight variations in the value of C_g or R_g which might occur due to temperature changes. Since the rest time is relatively long, a slight variation in discharge rate (as shown by the slope of the curves during discharge) will produce fairly large changes in rest time. This, in turn, causes large changes in PRF.

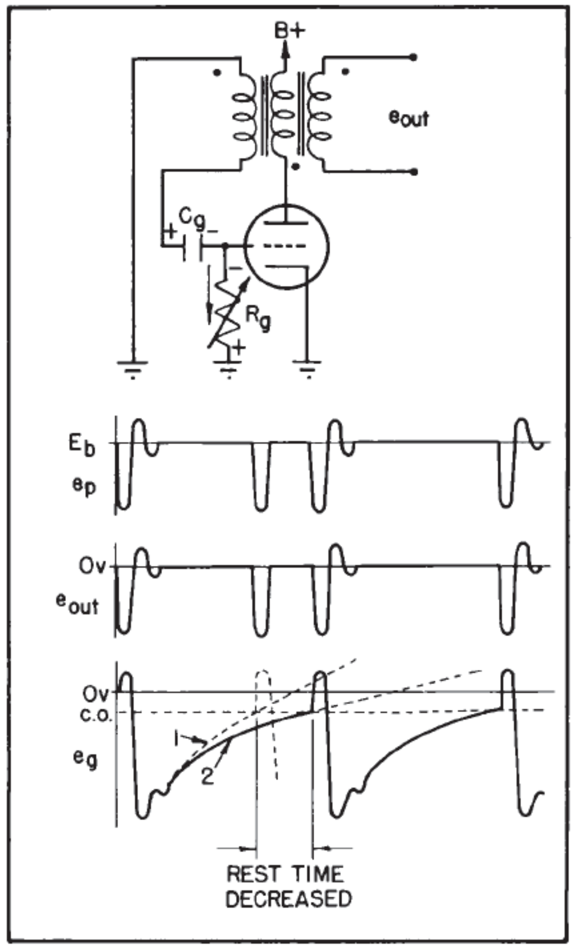

Figure 47-17 - Effect of small changes in C_g or R_g on PRF of free-running blocking oscillator.

A22. Due to the positive voltage induced in the grid transformer winding.

A23. When tube current is increasing at its fastest rate.

A24. The inductance of the pulse transformer.

A25. A combination of collapsing primary field inducing a negative potential in the grid winding and the discharge of C_g, both of which cause a high negative grid voltage forcing the tube to cut-off very rapidly.

A26. The collapsing field about the pulse transformer primary winding in series with the B+ source.

A27. Rest time decreases.

A28. To damp out oscillations after each output pulse.

The rate at which a capacitor discharges is a function of grid resistance and grid capacitance time constant. This rate is illustrated by the slope of the discharge curve. In Figure 47-17, it can be seen that if the normal discharge slope were increased, the effect of slight changes in the slope (due to R_g-C_g changes by temperature) would be reduced, thereby increasing stability.

A simple method of increasing circuit stability is to return R_g to B+ rather than to ground. This causes C_g to discharge from some negative potential toward B+ rather than ground. Since this represents a considerable increase in capacitor potential difference, discharge rate (and slope) will be greatly increased, as shown in Figure 47-18. Under this condition, slight changes in the value of R_g or C_g will have a smaller effect upon PRF than for the circuit in which R_g is returned to ground. It will be recalled that this same procedure was used in the free-running plate-coupled multivibrator previously studied. The result is improved PRF (STABILITY) for given temperature changes.

A better method of insuring frequency stability in a free-running oscillator is to cause oscillator action to occur as a result of accurate input SYNCHRONIZING PULSES or TRIGGERS. These sync triggers force the tube into conduction prior to the normal time required due to the grid capacitor discharge rate. Consequently, the synchronizing frequency must be slightly higher than the free-running frequency of the blocking oscillator.

Figure 47-19 shows a synchronized single-swing blocking oscillator. Note the only circuit

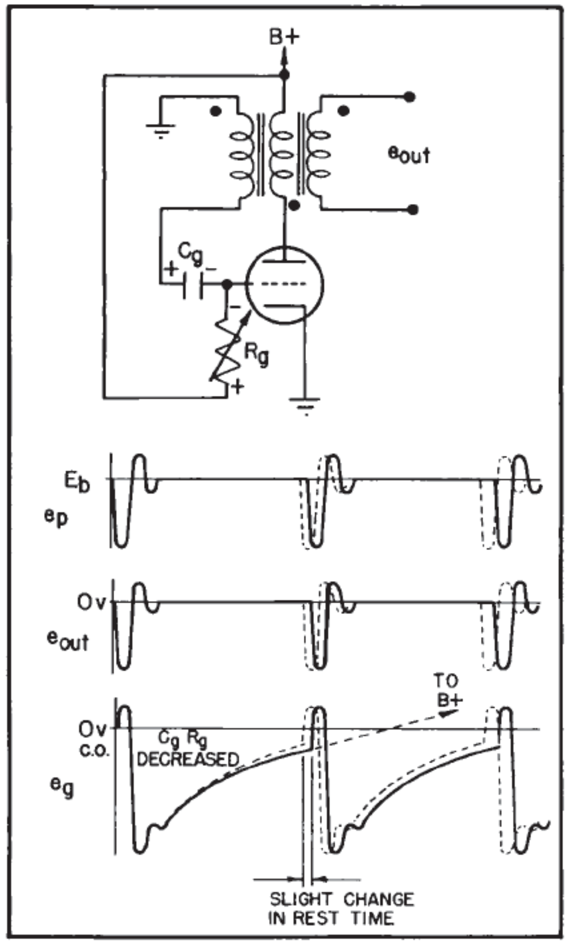

Figure 47-18 - Stabilized free-running blocking oscillator.

change is the addition of an input coupling capacitor. This capacitor can be connected either to the tube plate or grid, depending upon the polarity of the synchronizing triggers. If the sync triggers are positive, they are applied to the grid; if negative, they are applied to the plate. Through transformer action, the negative triggers applied to the plate will produce positive triggers in the grid circuit. The voltages e_p and e_{out} will be synchronized at the input sync frequency, which is slightly higher than the free-running frequency.

If the sync frequency is much higher than the free-running frequency, the circuit might synchronize itself with every second or third sync trigger. This has certain advantages. If a PRF of 500 pulses per second (PPS) is desired, the circuit could be synchronized with 1000 PPS triggers, making use of every second sync trigger. In this case, the free-running frequency

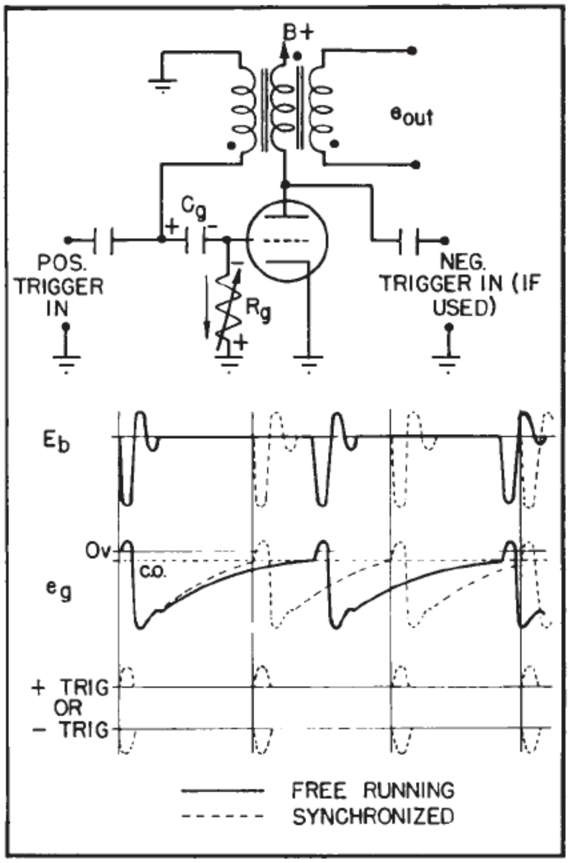

Figure 47-19 - Synchronized single swing blocking oscillator.

would be slightly less than 500 PPS. Since the output frequency is lower than the input synchronizing frequency; frequency division is said to have occurred.

Figure 47-20 illustrates the principle of frequency division in a synchronized blocking oscillator. It should be noted that the amplitude of the sync trigger must not exceed a given potential or the circuit will be triggered by every input sync pulse. A sync frequency lower than the free-running frequency is seldom used, since every output pulse would not be synchronized with a sync trigger. As a result, the rest time would vary between each succeeding output pulse so that some would be longer than normal while others would be shorter than normal. In most applications, variations in rest times are undesirable.

It has been shown that a free-running single-swing blocking oscillator can be triggered to produce outputs synchronized at a given frequency. If positive sync triggers are used, they are applied to the grid circuit while negative sync triggers are applied to the plate. The

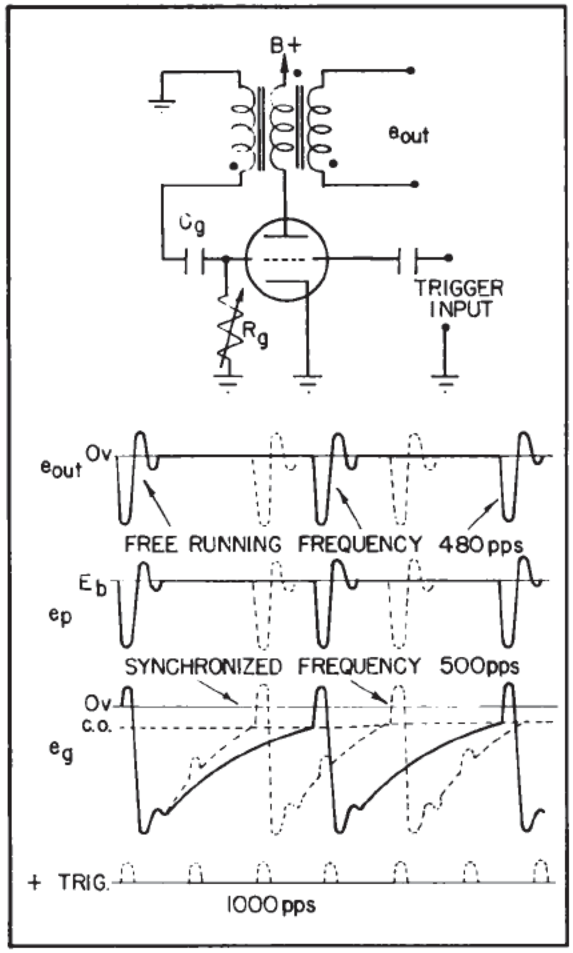

Figure 47-20 - Synchronizing a blocking oscillator with a multiple-frequency trigger.

sync frequency is usually higher than the free-running frequency of the oscillator. If trigger amplitude is kept at a proper level, frequency division can occur through the application of sync triggers which are some multiple frequency of the output. Through the use of sync triggers, the PRF of the oscillator is unaffected by slight variations in the value of C_g and R_g with the result that frequency stability is much better than for the unsynchronized free-running blocking oscillator.

Q29. Why are free-running blocking oscillators synchronized?

Q30. How can stability be improved without the use of synchronization?

A29. To stabilize the output frequency.

A30. By returning the grid resistor to B+, use of a regulated power supply and by use of temperature compensation.

Q31. Where would positive sync triggers be applied? Negative sync triggers?

Q32. Which frequency (free-running or sync) is normally lower? Why?

Q33. If multiple-frequency sync triggers are used, of what importance is their potential?

47-8. Driven Blocking Oscillator (Blocked Oscillator)

In many applications, a single-swing blocking oscillator is required which produces an output pulse only when triggered; that is, it is blocked or prevented from oscillating except when a trigger is applied. This blocking is usually accomplished by a circuit that biases (normally fixed) the tube beyond cut off until a trigger is applied. Such a circuit is called a driven blocking oscillator or a blocked oscillator. Figure 47-21 shows a typical driven blocking oscillator.

With the values shown in Figure 47-21, the voltage divider consisting of R_1 and R_2 will apply a positive 50 volts to the cathode. This makes the grid negative with respect to the cathode and the tube is cut off. The input trigger must be large enough to overcome the fixed bias and cause the tube to conduct.

The R_g C_g discharge time constant is not important to the operation of the circuit if frequency division is not used. As long as C_g is sufficiently discharged, the tube can be brought out of cut-off when the next trigger is applied. The fixed bias is sufficient to maintain the non-conduction operation of the circuit until the next trigger (or gate) is applied, without the use of the E_{rg} produced by R_g C_g time constant.

Refer to Figure 47-21, when trigger frequency is several times higher, shown in dotted lines, one trigger occurs during the R_g-C_g discharge time. The amplitude during this discharge time is insufficient to bring the tube out of cut-off, therefore frequency division will occur. This trigger can be applied to the grid (if positive) or to the plate (if negative). Capacitor C_1 is a cathode bypass capacitor to prevent degeneration when the tube conducts.

When a trigger is applied to the circuit, an output pulse is generated in the same manner as in a free-running blocking oscillator. However, upon completion of the output pulse when tube conduction is cut of by the discharge of C_g through R_g, fixed bias keeps the tube in a non-conducting state until the next trigger is applied. The output can be taken from a tertiary winding, grid, or from the plate, depending upon the polarity, amplitude, and shape of waveform desired.

By comparing the trigger and output waveforms in Figure 47-21, it can be seen that the output pulse is narrower than the triggering pulse. The time required for the output pulse to reach its maximum point is the time necessary for the tube to go from cutoff to the point where tube current can no longer increase. This point is where there is insufficient voltage difference in the tube to cause tube current to increase any further. This is nearly instantaneous, as shown by the sharp leading edge of the output waveform. Once the trigger overcomes the fixed bias the tube current starts and aided by the fast expansion of the primary field and induced volt-

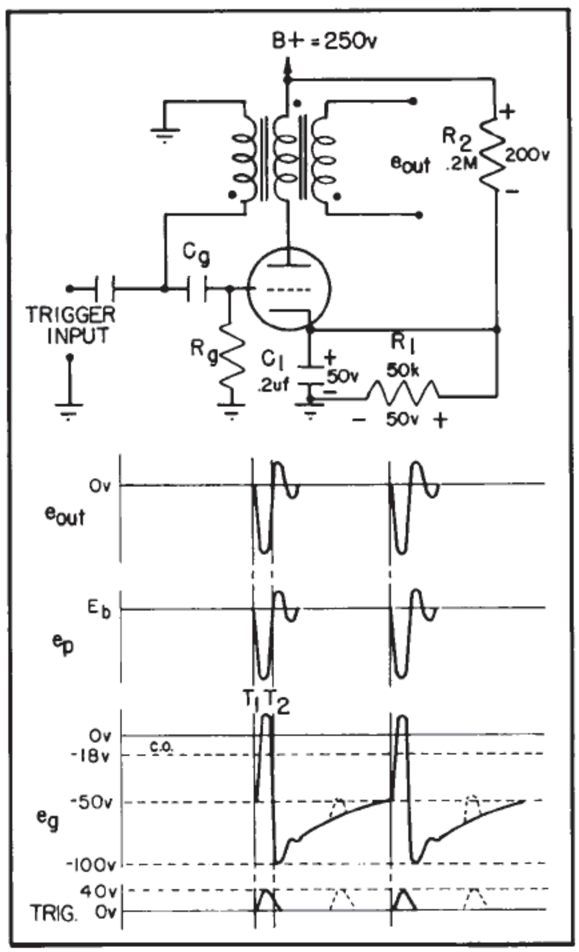

Figure 47-21 - Driven blocking oscillator.

age and fast charge time of C_g, tube current increases rapidly. The width of the pulse is determined by the time for tube conduction to go from its cutoff point to maximum and return to cutoff. From the diagram note the sharpness of the trailing edge of the output pulse. This time is determined by the time required for tube current to go from maximum to cutoff. This is aided by the 50 volt bias aiding the collapsing field. Since this 50 volt bias assists in tube cutoff, it can be seen that the output pulse ends before the trigger pulse has ended. Through the rapid action of the circuit, a narrow pulse with a steep leading and trailing edge is produced. It can be seen that the blocked oscillator has shaped the trigger pulse into a more usable form. It is in pulse-shaping circuits that blocked oscillators are frequently used.

The driven blocking oscillator, therefore, differs from a single-swing free-running blocking oscillator only in the fact that free-running action is prevented by biasing the tube beyond cutoff. Consequently, it must have an input trigger of sufficient magnitude to cause tube conduction and produce an output pulse. Usually, a voltage divider supplies the necessary biasing potential to maintain tube cutoff when no input trigger is applied.

Q34. Is the driven blocking oscillator free-running? Why?

Q35. Why is the trailing edge of the output pulse steep.

A31. Positive to the grid circuit, negative to the plate circuit.

A32. The free-running frequency is usually lower than the sync frequency. This is to insure that each output pulse is generated in synchronization with an input trigger so that the rest time between output pulses is constant.

A33. The potential must not be too large or too small, since inproper frequency division would result.

A34. No, because the tube is cut off by fixed-bias voltage which prevents free-running action.

A35. The steepness is determined by the time required for the tube to go from maximum conduction to cut off. Since the fixed bias aids the action of C_g in cutting off the tube, tube conduction will go from maximum to cut off very rapidly, and the output pulse will have a steep trailing edge.

EXERCISE 47

1. Why is the first alternation in the output of a ringing oscillator always negative?
2. In a ringing oscillator, what would be the tank frequency to provide 10 oscillations during a 1236 microsecond gating pulse?
3. What characteristics of the ringing oscillator circuit sustains oscillations while the tube is cut off?
4. If the cut-off potential of a switching tube used in a ringing oscillator were -14 volts, would a gating pulse of -15 volts cut the tube off? Explain.
5. If the filament of a ringing oscillator switching circuit were to open while the tube was conducting, what would be the output waveform?
6. The last alternation in the output of a ringing oscillator always has what polarity? Why?
7. What happens to the output pulse width if C_g is decreased in a self-pulsing blocking oscillator? Why?
8. What happens to PRF is R_g is decreased? Why?
9. In a self-pulsing blocking oscillator, what is the tank potential at the instant plate current becomes steady? Why?
10. How can the frequency of oscillations be increased in a self-pulsing blocking oscillator?
11. If a self-pulsing blocking oscillator produced continuous oscillations because of a maladjustment, what could be done to provice blocking action? Explain.
12. Why does a single-swing blocking oscillator produce only one oscillation before blocking action occurs?
13. What causes plate voltage in the single-swing blocking oscillator to go above B+?
14. Where can outputs be taken from a single-swing blocking oscillator?
15. Where would negative and positive sync triggers be applied, respectively, in a synchronized single swing blocking oscillator?
16. What is the normal relationship between the sync frequency and free-running frequency in a synchronized single-swing blocking oscillator?
17. If the desired PRF of a synchronized single-swing blocking oscillator is 1000 PPS, and the sync trigger frequency is 3000 PPS, what would be the free-running frequency?
18. What would happen to the output frequency of a synchronized single-swing blocking oscillator using a sync trigger frequency of 800 PPS to cause an output of 400 PPS?
19. How does the blocked oscillator differ from the synchronized single-swing blocking oscillator?
20. Of the various blocking oscillators, which provides the greatest practical range of output pulse repetition frequencies? Explain.

CHAPTER 48

CLAMPERS-CLIPPERS-COUNTERS

In this chapter, three types of circuits will be discussed. These circuits called CLAMPERS, CLIPPERS and COUNTERS are used in innumerable pieces of electronic equipment. Not the least of these applications is radar.

The first of these three circuits to be considered is the clamper.

48-1. Purpose of Clamping Circuits

A circuit that holds either amplitude extreme of a waveform to a given reference level of potential is called a CLAMPING CIRCUIT, or DC RESTORER.

Before discussing clamping circuits it is desirable to review briefly the action of coupling networks. In the coupling between stages in radio and radar circuits, a coupling capacitor is generally used to keep the high positive dc plate potential of the first tube isolated from the grid of the second tube. It is desirable that only the VARYING component of the plate potential be transmitted to the grid as a signal varying above and below some fixed reference level. If the lower end of the grid resistor is grounded, the signal varies above and below ground as shown in Figure 48-1. Thus the input of an ordinary RC coupling network is alternating in character about the average voltage level of the applied waveform. After the coupling capacitor charges to the average applied voltage, any decrease in applied voltage causes the output voltage of the RC network to swing negative. Any increase above the average causes the output voltage to swing positive.

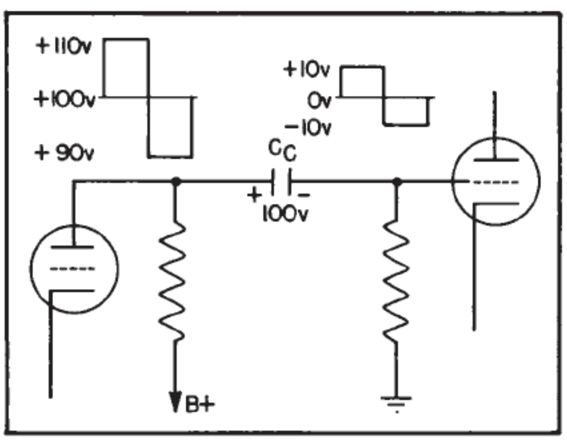

Figure 48-1 - RC coupling.

If a biasing potential is employed, the signal applied to the grid varies above and below this dc bias voltage as shown in Figure 48-2.

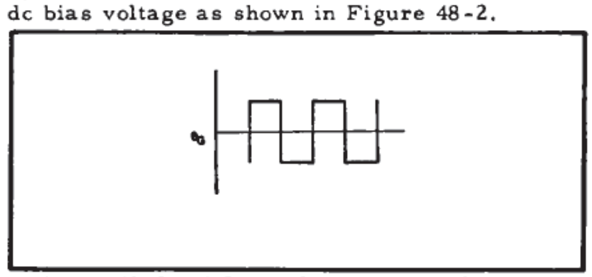

Figure 48-2 - RC coupling without clamping.

For a class A amplifier, the signal applied to the grid varies above and below some fixed reference level. The biasing potential is adjusted to the center of the class A range and the varying potential is kept within the limits of this range.

In other circuits, however, the waveform swing must be entirely above or entirely below the reference voltage, instead of alternating on both sides of it. For these applications a clamping circuit is used to hold either the extreme positive or the extreme negative of the waveform to the desired level as shown in Figure 48-3.

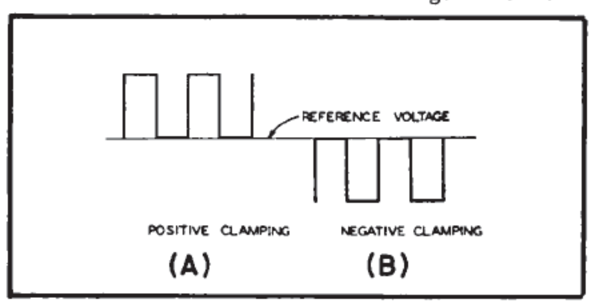

Figure 48-3 - Positive and negative clamping.

To obtain positive clamping, the maximum negative point of a waveform is positioned on some value of dc reference voltage in such a manner as to cause the entire waveform to lie in a more positive area than the reference voltage. This is shown in Figure 48-3A.

To obtain negative clamping, the maximum positive point of a waveform is positioned on

some value of dc reference voltage in such a manner as to cause the entire waveform to lie in a more negative area than the reference voltage as shown in Figure 48-3B.

Hence, a clamping circuit selects some dc reference voltage on which it positions a waveform. Clampers must not appreciably change the shape of a waveform in any manner. Any significant distortion which results from clamping is an indication of clamping circuit deficiencies in component types or values.

Q1. What is positive clamping?

Q2. Using normal RC coupling with R_g returned to ground, E_{in} is varied between +110 volts and +120 volts. What are the voltage extremes across R_g?

Q3. What is the primary function of a clamper?

48-2. Positive Diode Clamper (Unbiased)

The simplest type of clamping circuit utilizes a diode in conjunction with an RC coupling circuit, one arrangement (positive clamping) of which is shown in Figure 48-4. In this instance the capacitor voltage is maintained at approximately the minimum applied voltage.

To understand the action of this circuit the following points should be kept in mind: If the cathode of a diode is made negative with respect to the plate (or the plate positive with respect to the cathode), electrons flow from cathode to plate and the tube becomes a LOW RESISTANCE (in effect, a short circuit); if the cathode is made positive with respect to the plate, no current flows and the tube may be considered a HIGH RESISTANCE (in effect, an open circuit).

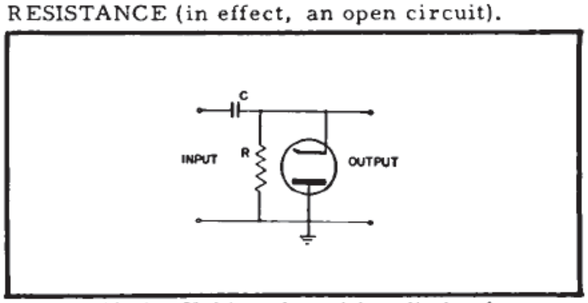

Figure 48-4 - Unbiased positive diode clamper.

Therefore, when the input waveform causes the diode to conduct, an extremely short time constant will be formed by the capacitor and the conduction plate to cathode resistance of the diode. This conduction resistance is approximately 500 ohms the low value of which results in C quickly charging to almost the input voltage.

When the input waveform is of such polarity that the diode does not conduct, a long time constant exists. This is due to the extremely high non-conduction plate to cathode resistance of the diode. Consequently, the capacitor will neither charge nor discharge appreciably and the output voltage will equal the sum of the input and capacitor charge voltages.

For clarity of circuit analysis, a 500 cps square wave whose amplitude varies from +50 volts to -50 volts is used in Figure 48-5. The capacitor, C, equals 0.1 microfarad and the resistor, R, equals 1 megohm. Assume the

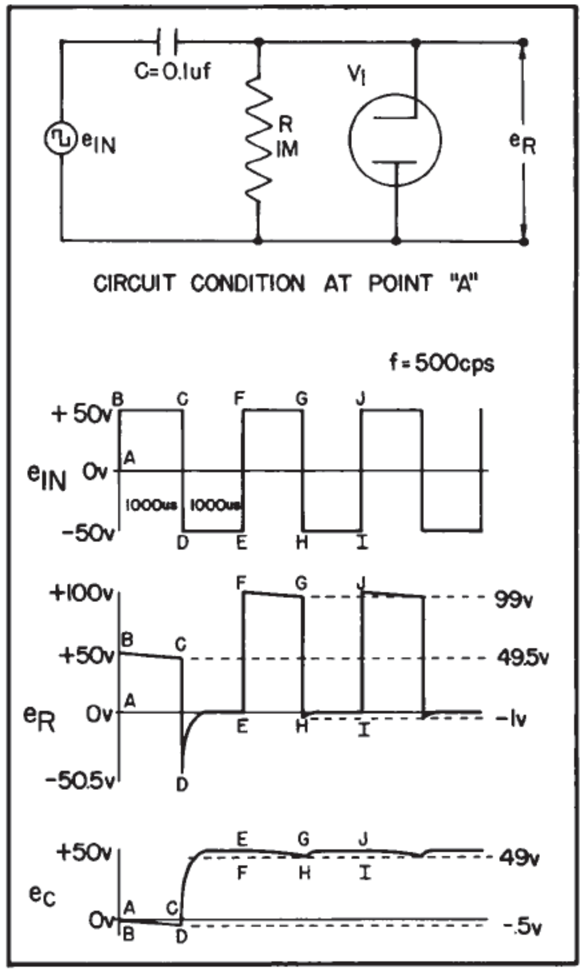

Figure 48-5 - Unbiased positive diode clamper with waveforms.

conduction resistance of the diode to be 500 ohms. $e_R = e_o$ in Figure 48-5 and the accompanying explanation will demonstrate the formula $e_{in} + e_C = e_o$ at any instant of time. As illustrated in Figure 48-5, when e_{in} is zero volts at point A, e_C equals zero volts and e_R equals zero volts. This is the condition in the unbiased positive diode clamper before an input is applied.

At point B on the input waveform, e_{in} is +50 volts. The diode will not conduct with a positive potential on its cathode and is effectively an open circuit. The voltage e_R will be equal to +50 volts and e_C will be equal to zero volts as shown in Figure 48-5 and Figure 48-6.

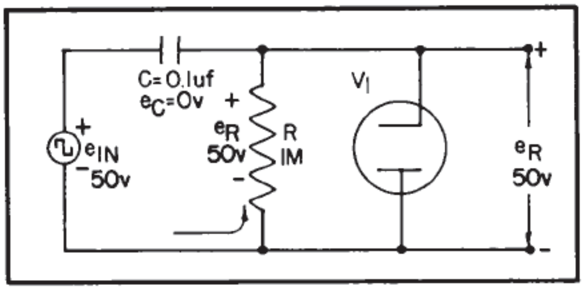

Figure 48-6 - Circuit conditions at point B.

The time duration of the +50 volt input alternation (B to C) is 1000 microseconds as shown in Figure 48-5. The capacitor attempts to charge during this time but the time constant of C and R equals ($0.1 \times 10^{-6} \times 1 \times 10^{6}$), or 100,000 microseconds. Therefore, the capacitor will charge for 1/100 of one time constant from point B to point C, and as illustrated on the waveforms in Figure 48-5 and in the circuit of Figure 48-7, the voltage e_C, can only increase to a fraction of a volt and e_R, the output, drops slightly.

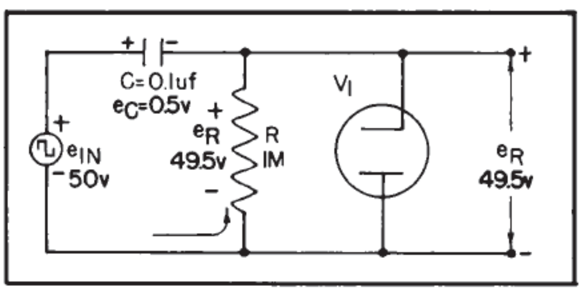

Figure 48-7 - Circuit conditions at point C.

At point D on the input waveform e_{in} has dropped to a -50 volts. The voltage, e_R, will drop to -50.5 volts because of the charge on the capacitor adding to e_{in} as shown in Figure 48-5 and 48-8. When the tube conducts, the total resistance in series with the capacitor will decrease to approximately 500 ohms. The time constant now is ($0.1 \times 10^{-6} \times 500$), or 50 microseconds. The time duration of the -50 volt input is 1000 microseconds, which makes the circuit a short time constant circuit.

The capacitor will charge to +50 volts in 250 microseconds - one-fourth of the time between points D and E. It will then retain that

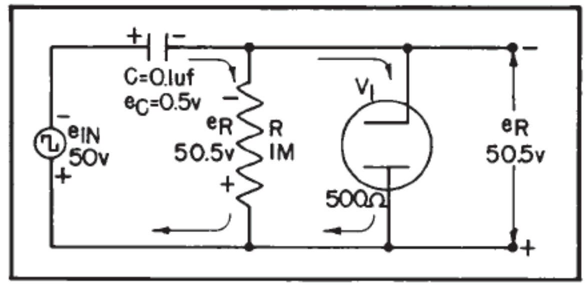

Figure 48-8 - Circuit conditions at point D.

charge until point E is reached. Just prior to capacitor discharge, e_C in reference is equal to +50 volts, e_{in} is equal to -50 volts, and e_R is equal to zero volts. This condition is illustrated in Figure 48-5 and 48-9.

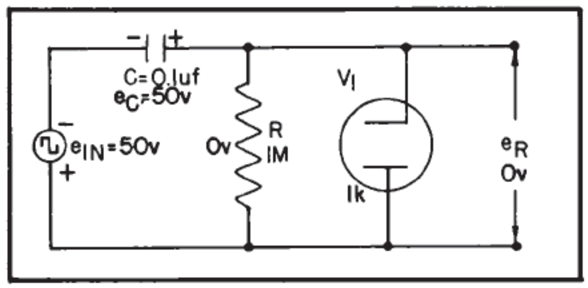

Figure 48-9 - Circuit conditions at point E.

At point F on the input waveform, e_{in} rises rapidly to +50 volts, and e_R increases from zero volts to +100 volts which is the sum of e_C + e_{in} as shown in Figure 48-5 and 48-10.

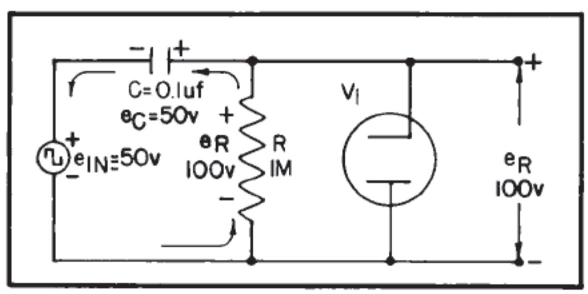

Figure 48-10 - Circuit conditions at point F.

If the tube were able to conduct, the capacitor would charge 50 volts in the opposite direction (a change of 100 volts). However, the circuit time constant is presently 100,000 microseconds. Since the time duration of the positive 50 volt input is 1000 microseconds, and the time from point F to point G is 1/100 of one time constant; the capacitor will only discharge approximately one volt of its total charge. Therefore, at point

A1. The electronic positioning of a waveform so that its most negative point rests on the dc reference voltage causing the entire waveform to fall in a positive region with respect to the reference voltage.

A2. +5 volts and -5 volts.

A3. To establish a reference level on which a waveform is positioned.

G, e_C equals +49 volts, e_{in} equals +50 volts, and e_R equals +99 volts as shown in Figures 48-5 and 48-11.

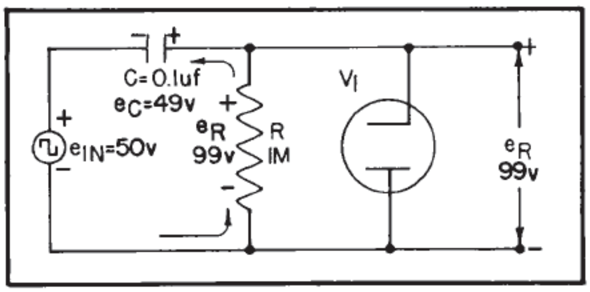

Figure 48-11 - Circuit conditions at point G.

At time H on the input waveform, e_{in} has dropped to -50 volts, e_C equals +49 volts; and e_R must drop to -1 volt as shown in Figures 48-5 and 48-12.

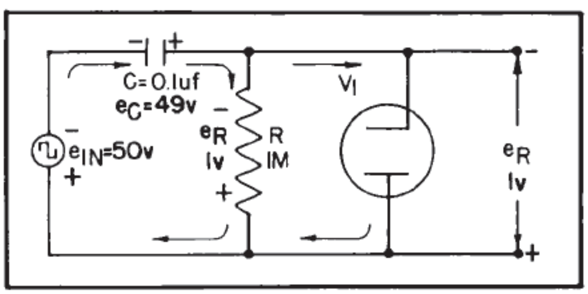

Figure 48-12 - Circuit conditions at point H.

At point H, diode conduction now provides a short time constant circuit of 50 microseconds. The capacitor rapidly recharges to +50 volts which returns the output voltage to its zero reference level. As demonstrated in Figure 48-5, these events occur long before time I.

At time J on the input waveform, e_{in} increases to +50 volts and e_R (e_o) rises to the sum of e_{in} + e_C or +100 volts.

As may be observed in Figure 48-5, there is some slight distortion of the output waveform during its first cycle. This initial cycle distortion does not persist after the capacitor reaches its +50 volt charge. Consequently, the output following the first cycle is an exact duplicate of the input waveform except that its most negative extremity is clamped on the dc reference point of zero volts.

Since the input voltage alternates between +50 and -50 volts, and the output voltage, e_o, alternates between zero volts and +100 volts, the circuit is identified as a zero bias positive clamper with a reference of zero volts.

In critical analysis, it can be determined that a minute portion of the output waveform extends below the zero reference level. This extension represents the recharge voltage of C immediately following the negative excursion of the input waveform. The duration of this spike is extremely short since during diode conduction C recharges rapidly.

The value of capacitor recharge voltage is determined by the voltage loss of C during diode non-conduction, and is a function of the value of R. As R is increased in value, capacitor recharge voltage decreases. Should, however, R be removed from the circuit or become infinite in value, the reference of e_o would vary with any change in amplitude of e_{in}. This is due to the inability of C to leak excess charge through R, thereby destroying the self-adjusting feature of a clamper circuit. Hence, some arbitrary value of R must be used in a clamper circuit.

The value of R should be sufficient to maintain the diode cut-off discharge of C at a minimum. In this manner, distortion of the output waveform is kept extremely low.

Circuit adjustment to amplitude changes (e_{in}) is better accomplished as R is reduced in value. Care must be taken in reducing R, lest with too low a value, differentiation should occur. The clamper circuit, therefore is a compromise as concerns the selection of a value of R. Small values of R aid circuit response to input amplitude changes. Large values of R minimize distortion. Normally, a large value of R is used as distortion is extremely undesirable.

Q4. Of what does the elementary clamper circuit consist?

Q5. On which alternation of e_{in} using a positive diode clamper circuit does the capacitor charge?

Q6. What level of distortion is acceptable in the output of a clamper circuit?

48-3. Positive Diode Clamper with Positive Bias

The positively biased positive diode clamper operates similarly to the unbiased clamper

with the exception that a bias is in the circuit. The most negative extremity of the output waveform is clamped to a reference which is the bias level. This is shown in Figure 48-13. Observe that with positive bias, the negative terminal of

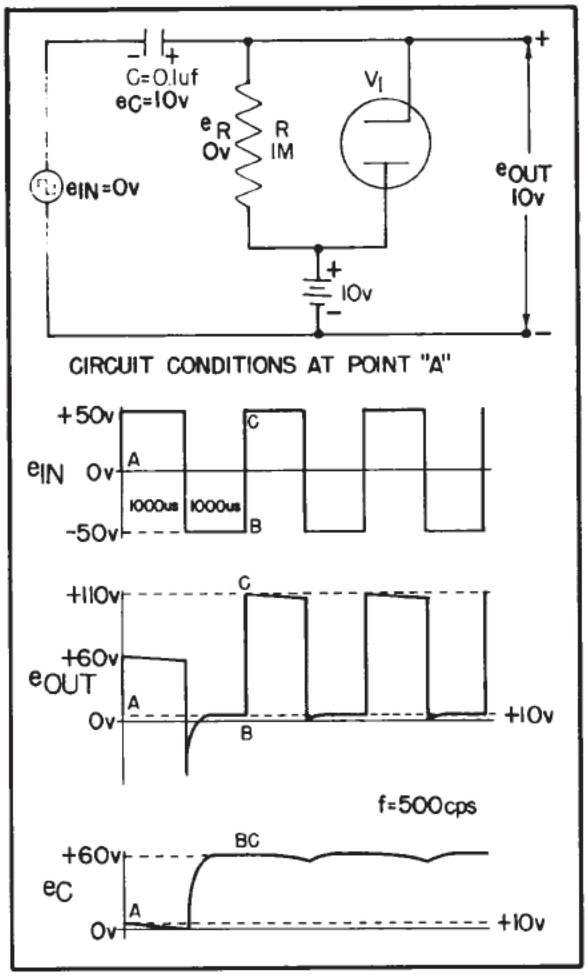

Figure 48-13 - Positive biased positive diode clamper with waveforms.

the battery is grounded.

With zero input to the circuit (Figure 48-13, point A), the capacitor can be considered to be charged to the bias level. Hence, the output is +10 volts ($e_{out} = e_C + e_{in}$).

On the first positive alternation of the input cycle, the diode is non-conducting and the output level increases to +60 volts, resembling the appearance of the input waveform. Because of the long time constant circuit the capacitor discharges but slightly.

When the input becomes -50 volts, a change of 110 volts, the diode conducts and the capacitor rapidly charges to +60 volts ($e_{bias} + e_{in}$) before diode conduction ceases. This is the circuit condition at point B Figure 48-14 on the input waveform. Observe that when e_C went to 60 volts, e_o returned to the reference level.

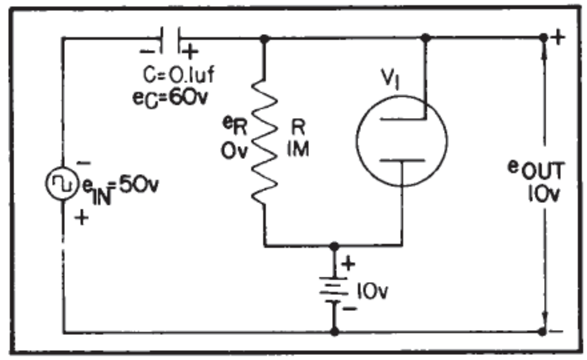

Figure 48-14 - Circuit conditions at point B.

At point C of the succeeding positive alternation of the input cycle, the diode is non-conducting and e_o = +110 volts ($e_{in} + e_C = e_o$). This is demonstrated in Figure 48-13 and 48-15.

From the foregoing analysis it can be observed that once e_C = +60 volts ($e_{in} + e_{bias}$), the output, will vary between +10 volts and +110 volts as the input varies between -50 volts and +50 volts. The characteristics of this circuit are the same as those of the unbiased positive diode clamper save that the reference (+10 volts) is established by the bias battery. As a consequence, the capacitor will at some time assume a charge of +60 volts which is the sum of the positive peak of the input cycle plus the bias voltage.

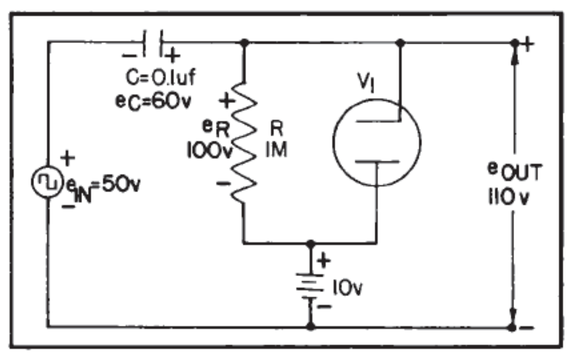

Figure 48-15 - Circuit conditions at point C.

Q7. To what reference will the most negative extremity of the input cycle be clamped when the signal is applied to a positive diode clamper with +5 volts bias?

Q8. A signal varying between -20 volts and +60 volts is applied to the circuit of question 7. What is the average charge of C? What are the output

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A4. A resistor, capacitor and diode.

A5. The negative alternation.

A6. An extremely negligible amount.

A7. +5 volts.

---

positive and negative waveform extremities? What is the output peak to peak amplitudes?

48-4. Positive Diode Clamper with Negative Bias

The negatively biased positive diode clamper differs from the positively biased positive diode clamper only in that the bias polarity is reversed thereby relocating the reference. The reference on which the most negative extremety of the output waveform is positioned now becomes the value of negative bias used in the circuit as shown in Figure 48-16.

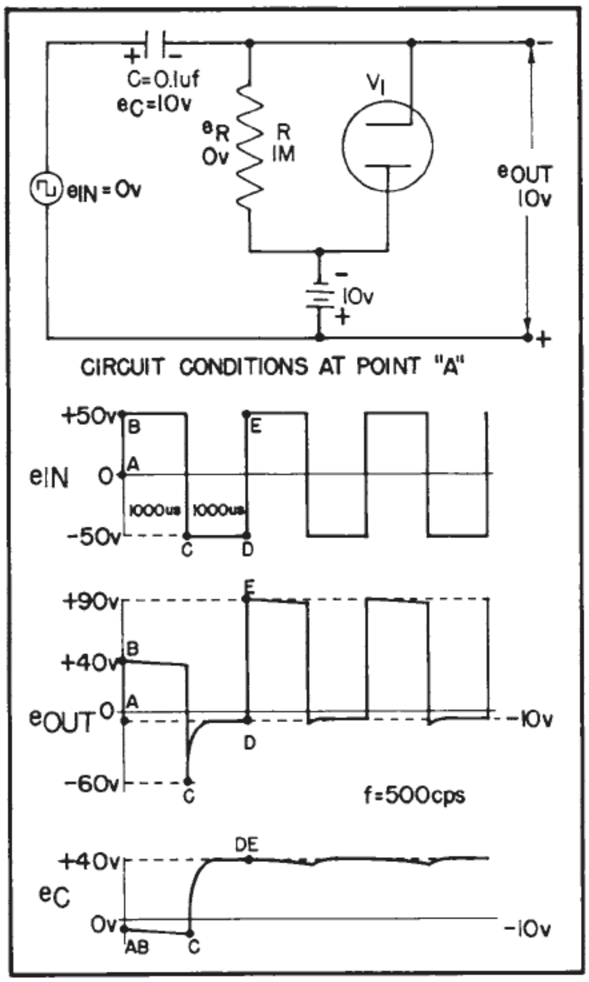

Figure 48-16 - Positive diode clamper with negative bias.

Referring to Figure 48-16, observe that the capacitor is charged to the bias level when e_{in} is zero (point A on the input). This is true because the generator (e_{in}) provides a charge path through its internal resistance. Therefore, the output voltage at this instant is -10 volts ($e_{in} + e_C = e_o$).

At point B e_{in} rises to +50 volts, e_o increases from -10 volts to +40 volts or to the value of $e_{in} + e_C$. During this time, the diode is non-conducting and the time constant is long, causing the capacitor to discharge only slightly.

At point C on the input waveform in Figure 48-16, the input is once more -50 volts. The instantaneous output is -60 volts with respect to the plate as shown in Figure 48-17. During this very short time constant, the 50 volt charge across the capacitor occurs as was shown in Figure 48-16. The capacitor now charges to 40 volts, (Figure 48-18) and the output is -10 volts ($e_{in} + e_C = e_o$).

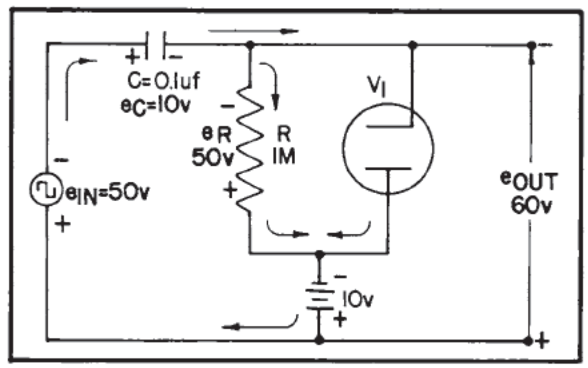

Figure 48-17 - Circuit conditions at point C.

When e_{in} rises again to +50 volts at point E (Figures 48-16 and 48-19), e_o rapidly increases from -10 volts to +90 volts ($e_{in} + e_C = e_o$). Due to the long time constant circuit during diode non-conduction, the capacitor will discharge but slightly.

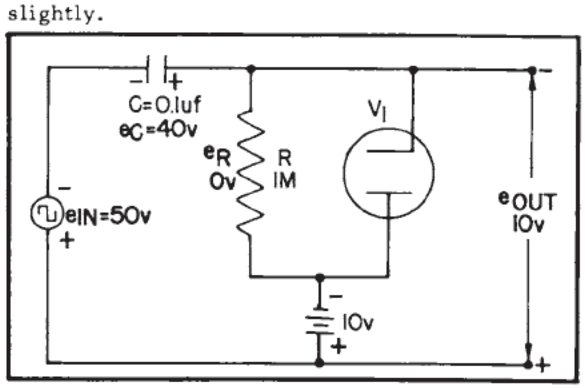

Figure 48-18 - Circuit conditions at point D.

Therefore, as e_{in} varies between -50 and +50 volts at point E (Figures 48-16, 48-19), e_o rapidly increases from -10 volts to +90 volts. Circuit action is similar to that of an unbiased clamper.

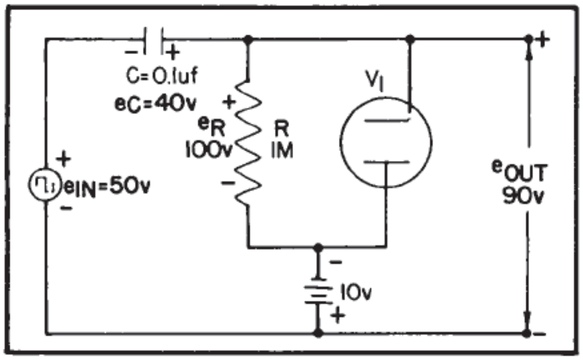

Figure 48-19 - Circuit conditions at point E.

Q9. In a positive diode clamper with a -15 volt bias, what is the reference. Which extremity of the output waveform is clamped to the reference?

Q10. A varying signal of -25 volts to +25 volts is applied to the circuit of question 9. What are the positive and negative extremities of the output waveform?

48-5. Negative Diode Clamper (unbiased)

The principle difference between the unbiased positive and negative clamper circuits is the manner in which the diode is connected. In the positive clamper, the anode of the diode was connected to the reference. Negative clampers differ from positive clampers by the fact that the cathode of the diode is connected to the reference (see Figure 48-20). In this manner, the output waveform will have its most positive extremity clamped to the reference. Stated otherwise, the entire output waveform will lie in a more negative area than the reference. This is shown in Figure 48-21. The diode in the negative clamper conducts upon the application of the positive alternation of the input waveform, providing a path for rapid charging of the capacitor. This corresponds to a short time constant circuit. Upon application of the negative alternation of the input signal, the diode is non-conducting and the output voltage is the sum of the negative alternation of the input signal. The diode is non-conducting, and the output voltage is the sum of the charge on the capacitor during the positive alternation, and the magnitude of the negative alternation (e_C + e_{in}). A high value of resistance is utilized

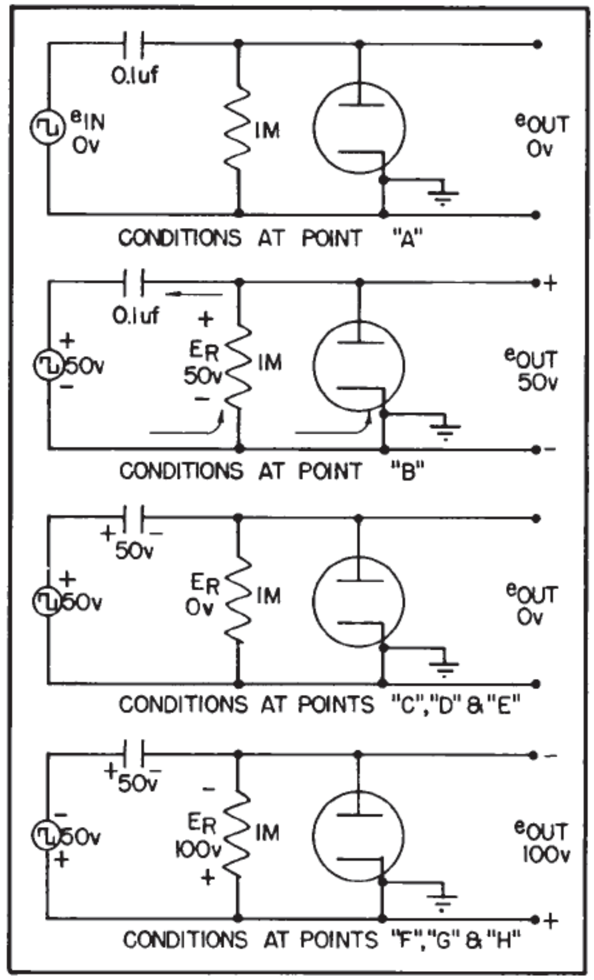

Figure 48-20 - Negative diode clamper (unbiased).

to prevent the capacitor from discharging appreciably during the period in which the diode is non-conducting. This corresponds to a long time constant circuit.

The circuits in Figure 48-20 and waveforms in Figure 48-21 clarify the action of the unbiased negative clamper. On the first positive alternation of the input signal, the diode conducts, and the capacitor charges rapidly to a potential of -50 volts. After the capacitor is charged, the output remains at zero volts (e_{in} + e_C). On the negative alternation of the input signal the diode is non-conducting. During this period, the capacitor does not discharge appreciably through the one megohm resistor. Accordingly, the output voltage (e_o) decreases to a negative 100 volts (e_{in} + e_C) at times F, G, H; and remains at this level during the entire duration of the negative input alternation. As in the basic

A8. +25 volts, +5 to +85 volts, 80 volts.

A9. -15 volts, the most negative extremity.

A10. +35 volts and -15 volts.

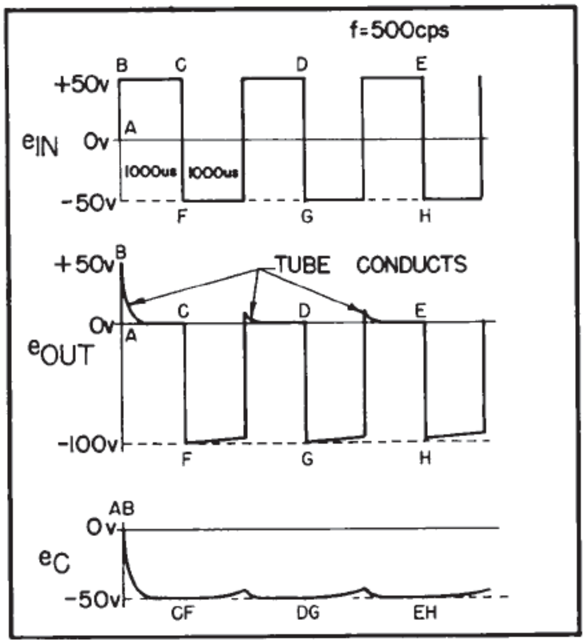

Figure 48-21 - Waveforms for negative unbiased clamper.

unbiased positive diode clamper, the value of the resistor in the unbiased negative diode clamper must be large to avoid output waveform distortion.

Q11. On what alternation of the input waveform would the diode in the negative clamper conduct?

Q12. When the diode in the negative clamper does not conduct, what does the output voltage equal?

48-6. Negative Diode Clamper with Negative Bias

A biased negative clamper operates in the same manner as the biased positive clamper. A negative diode clamper with a -10 volts bias as shown in Figure 48-22 will clamp the upper extremity of the waveform at a -10 volts rather than zero volts.

With zero volts input at point A of the input waveform shown in Figure 48-23, the capacitor is initially charged to the value of bias voltage

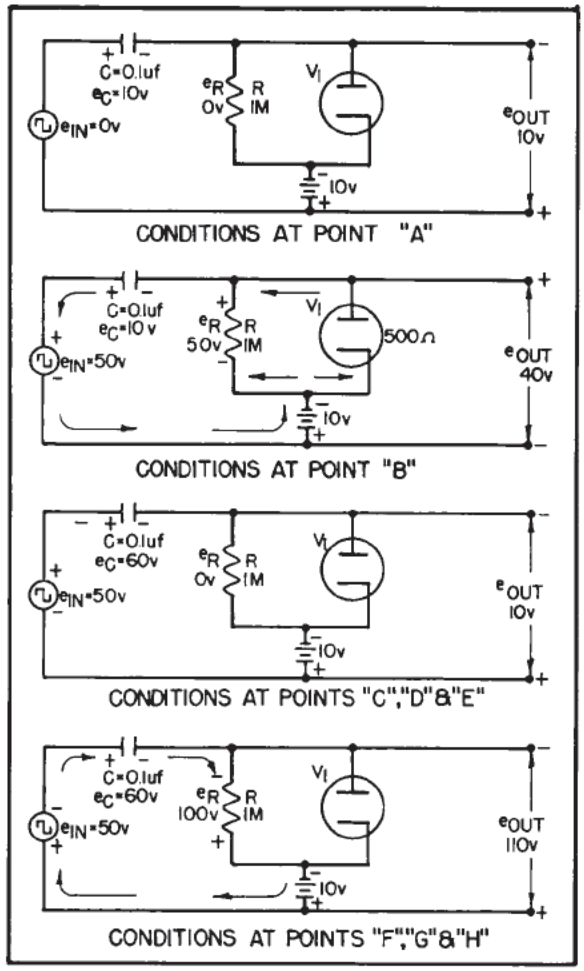

Figure 48-22 - Negative diode clamper with negative bias.

(-10 volts) through the source resistance. The output voltage (e_o) at that time is -10 volts (e_{in} + e_C). When the input waveform initially goes positive for the first time at point B, the capacitor rapidly charges through the low forward resistance of the conducting diode to -60 volts (e_{in} + e_{bias}). As indicated by Figure 48-23, the capacitor is charged to a -60 volts long before point C (the end of the first positive alternation), and the output voltage returns to -10 volts. On subsequent alternations, the input signal is in a negative direction (points F, G, and H), the diode is non-conducting, and the charge on the capacitor remains relatively constant. The output voltage (e_o) is approximately -110 volts (e_C + e_{in}) during the duration of the negative input alternations. Whenever the input signal goes positive, the diode conducts, causing the capacitor to charge rapidly to

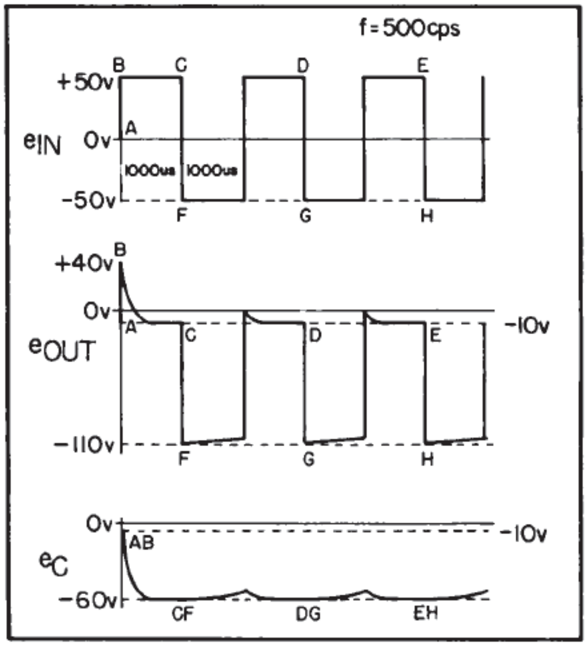

Figure 48-23 - Waveforms for biased negative clamper.

negative 60 volts, and the output to return to -10 volts. As a result of this circuit action, the most positive extremity of the waveform is clamped to the negative 10 volt reference.

Q13. In the clamper circuit in Figure 48-22, why does e_{out} equal -10 volts when e_{in} is +50 volts?

Q14. If a biased negative diode clamper had a -15 volts bias and an input waveform with a peak-to-peak value of 80 volts, what is the value of the upper and lower extremities of the output waveform?

48-7. Negative Diode Clamper with Positive Bias

A negative diode clamper is shown in Figure 48-24 with positive bias.

With zero volts input at point A on the input waveform, the capacitor is charged to the bias voltage and e_{out} is +10 volts. When the input goes to 50 volts (point B), the capacitor charges rapidly to -40 volts, the sum of e_{in} and the bias voltage. The charge path is through the low forward resistance of the conducting diode. The output voltage after the capacitor has made this charge returns to a value of +10 volts. On all subsequent negative alternations of the input signal (points F, G, and H), the diode is non-conducting; and e_{out} equals -90 volts (e_{in} + e_C). Whatever small amount the capacitor is able to discharge during the negative alternations of the input is quickly replenished when the tube conducts on the positive swing of the input voltage. Thus with the input varying from -50 volts to +50 volts, the output varies from +10 volts to -90 volts as shown in Figure 48-24. The positive most extremity of the waveform has been clamped to the +10 volt bias reference.

Q15. A negative diode clamper with a battery for positive bias would have which terminal of the battery grounded?

48-8. Grid Clamping

Clamping may be performed at the grid of an ordinary triode or pentode as well as in a diode. Any element of an electron tube, if made positive with respect to the cathode, attracts electrons from it. On the other hand, any element made negative with respect to the cathode repels

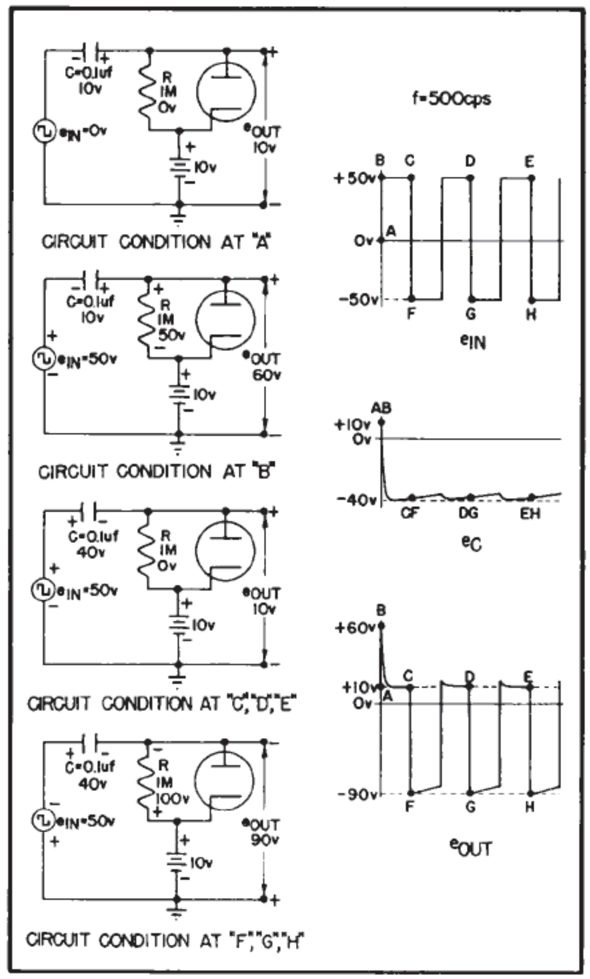

Figure 48-24 - Negative diode clamper with positive bias.

A11. On the positive alternations.

A12. The output voltage equals the input voltage plus the voltage on the capacitor.

A13. Because the capacitor quickly charges through the low resistance of the conducting diode to -60 volts (the sum of the input voltage and the bias voltage, and the output equals e_{in} plus e_C or -10 volts.

A14. -15 volts and -95 volts.

A15. The negative terminal.

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electrons and has no current flow. Thus, the grid of a tube, connected as shown in Figure 48-25 acts as the plate of a diode circuit. Any tendency of the grid to go positive causes grid

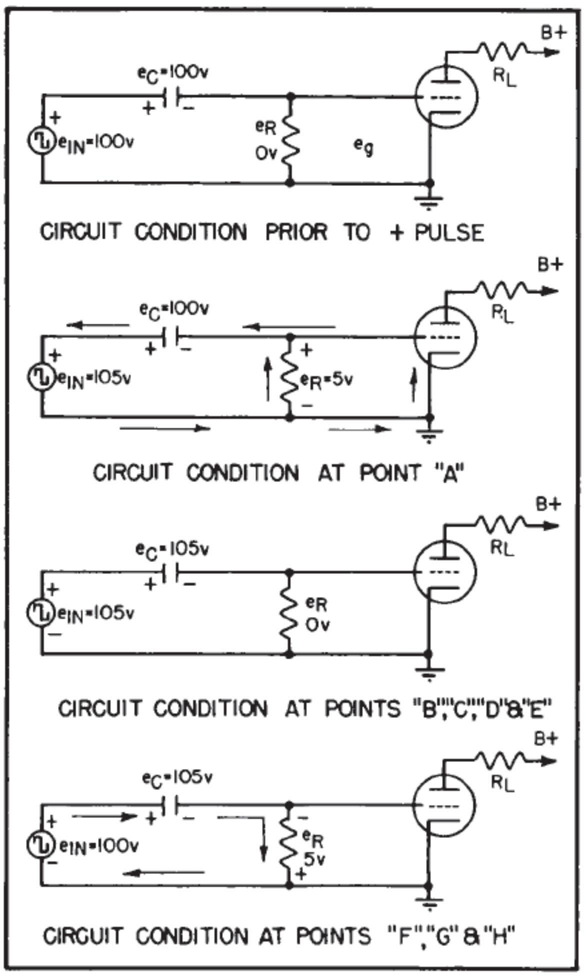

Figure 48-25 - Grid clamping circuit.

current to flow, charging C quickly to the applied potential through the low resistance conducting path. Once the capacitor has charged to the most positive value of the input voltage, e_g will equal zero volts as shown in Figure 48-26, (points B, C, D, E). When the input voltage, which can be the plate waveform from a previous amplifier, decreases to +100 volts; the voltage on the grid drops to a -5 volts (e_C + e_{in}). The capacitor can not rapidly discharge through R because of the long time constant and the grid voltage remains at -5 volts during the time the input voltage is +100 volts.

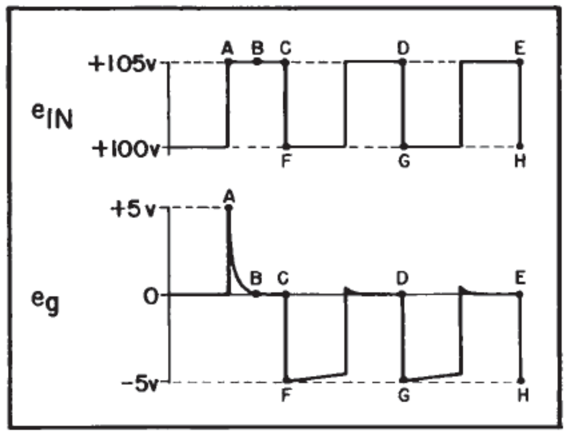

Figure 48-26 - Grid clamper waveforms.

It can be seen that the upper extremity of the grid waveform is clamped to zero volts. The action of the grid clamping is the same as that of the negative diode clamper discussed previously.

Q16. A grid clamper is what type of clamper?

48-9. Application of Clamping Circuits

In practice, clamping usually is encountered in sweep circuits. If the sweep voltage does not always start from the same reference point, the trace itself does not begin at the same point on the screen each time the cycle is repeated, and is therefore jittery or erratic. If a clamping circuit is placed between the final sweep amplifier and the deflection element, the voltage from which the sweep signal starts can be regulated by adjusting the dc voltage applied to the clamping circuit.

One circuit that is typical of the clamping circuits used in cathode-ray oscilloscopes is shown in Figure 48-27. The beam of the cathode-ray tube, V_3, is deflected by the push-pull sawtooth voltages shown. The beam therefore traces a bright line on the screen when it is moved from left to right at uniform speed, starting at point A. At the end of the sweep, the

beam is moved very quickly from point B back to point A. The function of the clamping circuit is to force point A to remain at the same place on the screen even though amplitude variations may occur in the applied sawtooth wave. In Figure 48-27, the resistors R_4 and R_6 form a voltage divider which applied +200 volts to the left deflection plate (d_1). R_5 and the variable resistor, R_3, provides anywhere from +100 volts to +300 volts for the right deflection plate (d_2). By varying the dc voltage on the right deflection plate (d_2), the trace or dot on the CRT can be positioned horizontally. Thus, R_3 is the HORIZONTAL POSITION CONTROL.

Assume that no sweep voltage is applied, and only a dot is seen on the CRT. If the arm of the resistor, R_3, was set at the center of R_3, the dc voltages on the deflection plates would be equal and the dot would be centered. If the arm of R_3 was all the way to the left of R_3, the right deflection plate (d_2) would be 100 volts more positive than the left deflection plate (d_1), and the dot would be positioned to the right.

With the arm of R_3 positioned as shown in Figure 48-27, (d_1) is 100 volts more positive than (d_2), and the dot is positioned on the left side of the screen. It can be seen that if the dot is to move from left to right when a sweep voltage is applied, the arm of R_3 should be near its minimum setting.

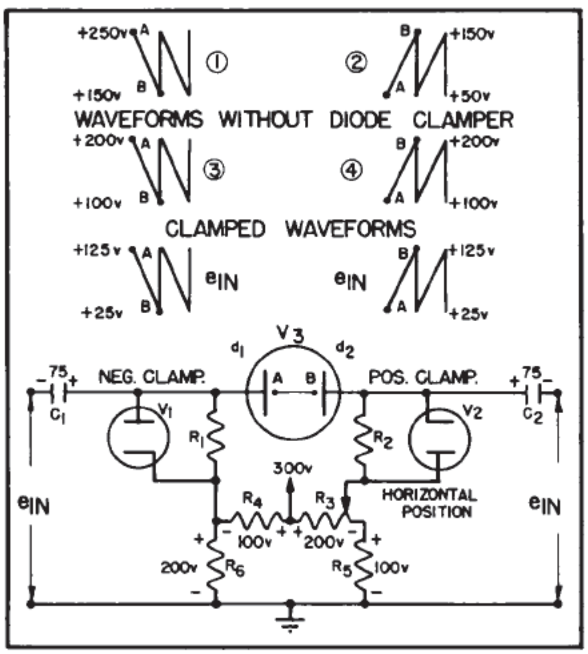

Figure 48-27 - Typical application of clampers.

The input to C_1 in Figure 48-27 is a negative going sawtooth waveform varying between +125 and +25 volts. The input to C_2 is a positive going waveform varying between +25 and +125 volts. These waveforms could not be applied directly to the deflection plates without interfering with the horizontal positioning system. If they were applied by RC coupling without diode clampers, as illustrated by waveforms 1 and 2 in Figure 48-27, and if their amplitudes were to vary, the starting point would also vary. The clamper consisting of V_1, C_1 and R_1 clamps the waveform applied to d_1 below the +200 volt reference established by the voltage drop across R_6. Therefore, the waveform applied to d_1 will always start at +200 volts at point A regardless of its amplitude.

The clamper consisting of V_2, C_2, and R_2 clamps the waveform applied to d_2 above the +100 volt reference established by the setting of the arm of R_3. Thus, the waveform applied to d_2, with the arm of R_3 positioned as shown in Figure 48-27, will always start at the +100 volt reference regardless of its amplitude.

From this analysis, it is evident that the centering system furnishes the bias for the clampers, and that the trace on the CRT will always begin at the same point on the screen regardless of the amplitude of the sawtooth waveforms.

Q17. Why is clamping often used when applying a sawtooth voltage waveform to the horizontal deflection plates of the CRT?

Q18. What type of clamper is V_1, C_1, and R_1 in Figure 48-27, and what type of bias is used?

Q19. What type of clamper is V_2, C_2, and R_2 in Figure 48-27, and what type of bias is used?

48-10. The Purpose of Limiting Circuits (Clippers)

The term LIMITING refers to the removal by electronic means of one extremity or the other of the input wave. Circuits which perform this function are referred to as limiters or clippers.

Limiters are useful in waveshaping where it is desirable to square off the extremities of the applied signal. A sine wave may be applied to a limiter to obtain a rectangular wave. A peaked wave may be applied to a limiter to eliminate either the positive or the negative peaks from the output. In frequency modulation receivers, where it is necessary to limit the amplitude of the signal applied to the detection system to a constant value, limiter circuits are employed. Limiters find application as protective devices in circuits which the input voltage to a stage must be prevented from swinging too far in the positive or the negative direction.

A16. A negative clamper.

A17. To insure that the trace on the CRT will always start at the same point.

A18. A negative clamper with positive bias.

A19. A positive clamper with positive bias.

Q20. What function does a clipper perform?

48-11. Series Diode Limiting

The characteristics of a diode are such that the tube conducts only when the plate is at a positive potential with respect to the cathode or, in other words, when the cathode is negative with respect to the plate. If the cathode is held at ground potential the plate need only be positive with respect to ground for current to pass through the diode. A positive potential may be placed on the cathode, in which case the diode does not conduct until the voltage on the plate rises above an equally positive value. Likewise, the cathode may be held at a negative potential and the diode conducts when the plate is positive with respect to the cathode and continues to conduct while the plate is at this negative potential which is less than the negative potential on the cathode. As the plate becomes more positive with respect to the cathode, the current through the tube increases and the plate-to-cathode resistance decreases rapidly from an open circuit to an average value on the order of 500 ohms.

The series-diode limiter (diode in series with the load) shown in Figure 48-28 is commonly used to limit the positive half of a sine wave. The rectifying action of the diode is utilized in a manner so that it may be termed a switch. This is justified if the value of R is very large as compared to the resistance of the diode when conducting. Thus, in Figure 48-28, the output voltage remains at zero throughout the positive half cycle of the input since the diode switch is open and no current flows through R.

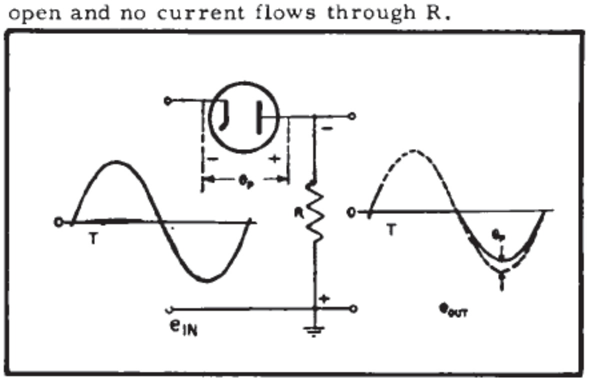

Figure 48-28 - Series diode used to limit positive signals.

During the next half cycle, on the other hand, the cathode is negative with respect to the plate, and the diode conducts. The switch is closed and the output voltage developed across R follows the applied voltage and, neglecting the very small drop across the diode e_P, is essentially equal to it.

In a similar manner the same circuit, with the diode connections reversed, may be used to limit the negative swing of the input voltage. This application is illustrated in Figure 48-29. The diode switch is closed during the positive swing of the input voltage and is open during the negative swing. Thus a voltage is developed across R during the positive half cycle only.

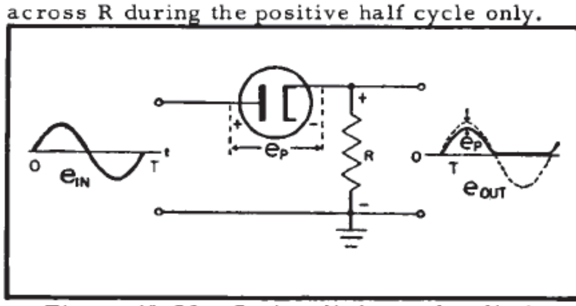

Figure 48-29 - Series diode used to limit negative signals.

Q21. What circuit conditions must exist in a series diode limiter in order to obtain an output?

Q22. Which alternation of the input waveform causes the diode to be non-conducting in a series negative diode limiter?

48-12. Parallel Diode Limiters (unbiased)

An alternate method of employing diodes in limiter circuits is shown in Figure 48-30. The diodes in the two circuits, A and B, are connected in parallel with the load, which is assumed to be a very high impedance so that the output current is negligible.

In Figure 48-30A, the diode is connected so as to limit the positive signals at approximately ground potential. Since the cathode is held at ground potential, the diode conducts throughout the entire positive half cycle. Current flows through the diode and through the series resistor, R. As R is large as compared to the plate-to-cathode resistance of the diode, essentially the entire output voltage is developed across R and the output voltage is only the very low voltage drop across the diode, e_P. This may be a negligible positive voltage depending on the ratio of R to the diode resistance. On the negative swing of the input, the diode does not conduct; thus no current flows through R and the output voltage equals the input.

In Figure 48-30B, the plate of the diode is held

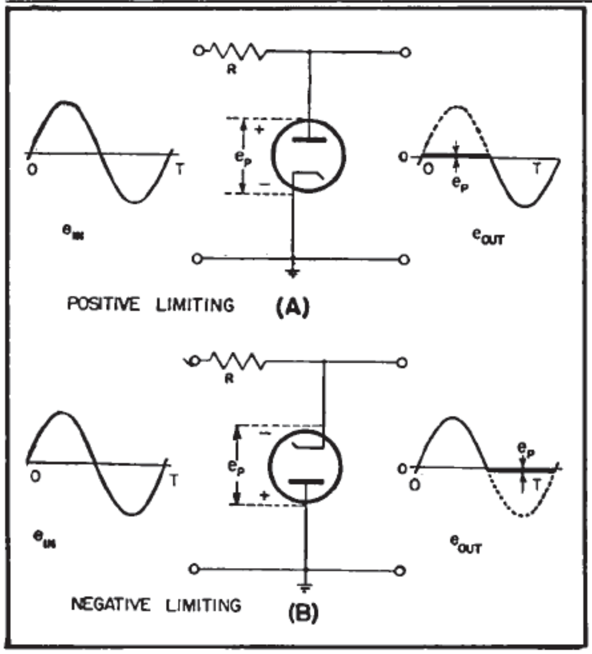

Figure 48-30 - Parallel-diode limiter circuit.

at ground potential so that the diode does not conduct during the positive half cycle. Thus the output voltage equals the input. During the negative half cycle of the input voltage, the cathode is negative with respect to the plate and the diode conducts. The diode current flows through the series resistance R across which essentially the entire output voltage is developed. The output voltage is limited to the very low voltage drop across the diode. This low negative voltage as a rule may be neglected and in this and the previous examples, the outputs may be considered as being limited at essentially ground potential as a result of the switching action of the diode.

Q23. Is the diode conducting or non-conducting in a parallel diode limiter when the limiting action occurs?

Q24. What should the ohmic value of the resistor used in a parallel diode limiter be with respect to the conducting resistance of the diode?

48-13. Biased Parallel Diode Limiters

An input voltage can be limited to any desirable positive or negative value by holding the proper diode electrode at that voltage by means of a battery or a biasing resistor. In Figure 48-31, two such circuits are shown.

The cathode of the diode in Figure 48-31A is more positive than the plate by the value of E when no signal is applied at the input. As long as the input voltage remains less positive than

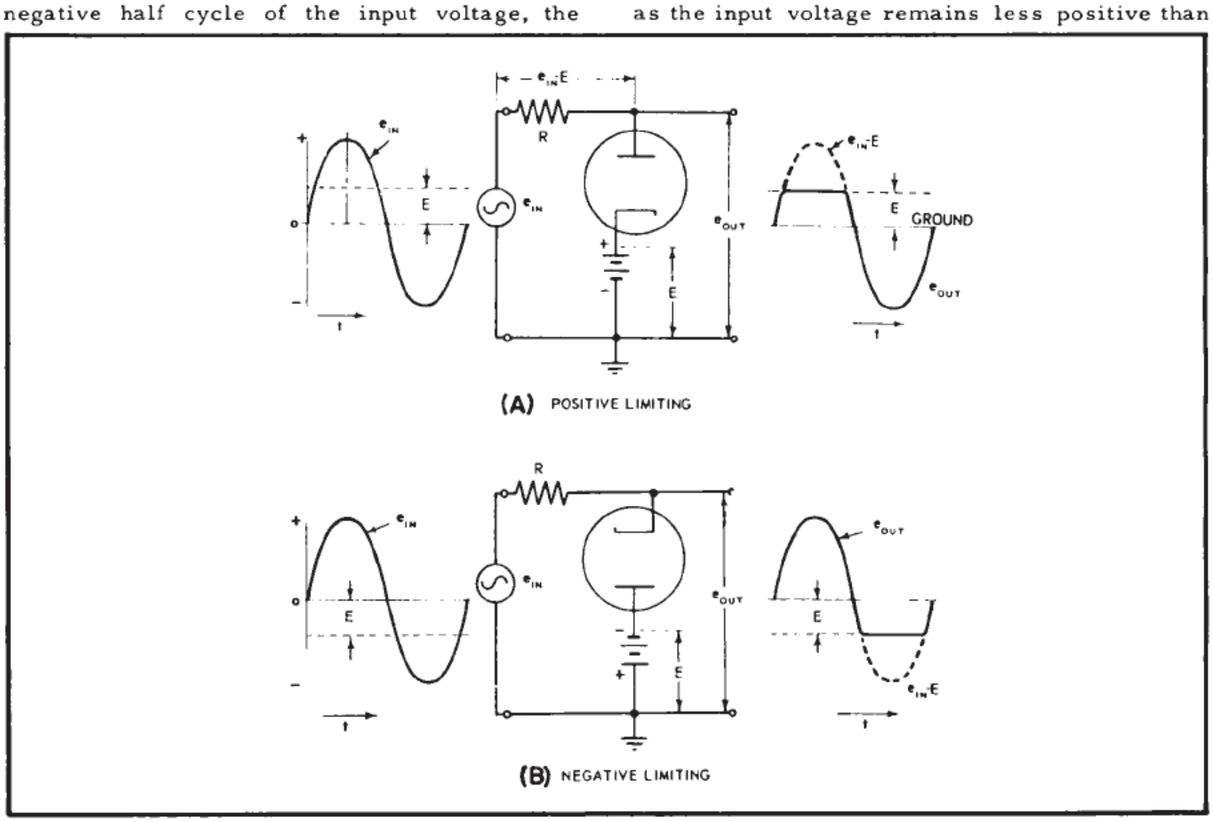

Figure 48-31 - Parallel diodes limiting above and below ground potential.

A20. A clipper performs the function of removing one extremity of an input waveform.

A21. The diode must conduct.

A22. The diode is non-conducting on the negative alternations.

A23. The limiting action occurs when the diode is conducting.

A24. The ohmic value should be very large.

---

the battery voltage, E, the diode acts as an open switch and the output equals the input. If the input increases to a value greater than E, the diode conducts and behaves as a closed switch which effectively connects the upper output terminal to the positive terminal of the battery. Thus during the portion of the input cycle, the output voltage equals E and the difference between e_{in} and E appears as an i_R drop across the resistor, R, neglecting e_p.

The plate of the diode in Figure 48-31B is negative by the value of battery voltage E. Thus as long as the input is positive or is less negative than E the diode is an open switch and the output voltage, e_{out}, is equal to the input. When the input becomes more negative than E, the diode conducts and effectively connects the upper terminal to the negative terminal of the battery. During this portion of the input cycle, e_{out} equals E and the difference between e_{in} and E appears as an i_R drop across R.

It is sometimes desirable to pass only the positive or negative extremity of a waveform on to a succeeding stage. To accomplish this, the parallel-diode limiters shown in Figure 48-32 can be employed. In A, the entire portion of the input waveform above the negative potential, E, causes the diode to conduct, thus producing an output voltage which varies between the negative level of E and the negative extremity of the input. In B, the diode conducts during the entire portion of the input waveform which is below the positive potential of E. The output voltage then varies between the positive level of E and the positive extremity of the input waveform. In either case, the difference between the value of E and e_{in}, during the time the diode conducts, is represented by the i_R drop across the series resistor, R.

Q25. What portion of the input waveform is clipped by a positive parallel diode limiter with 5 volts positive bias?

Q26. When does the limiting action take place in a negative parallel diode limiter?

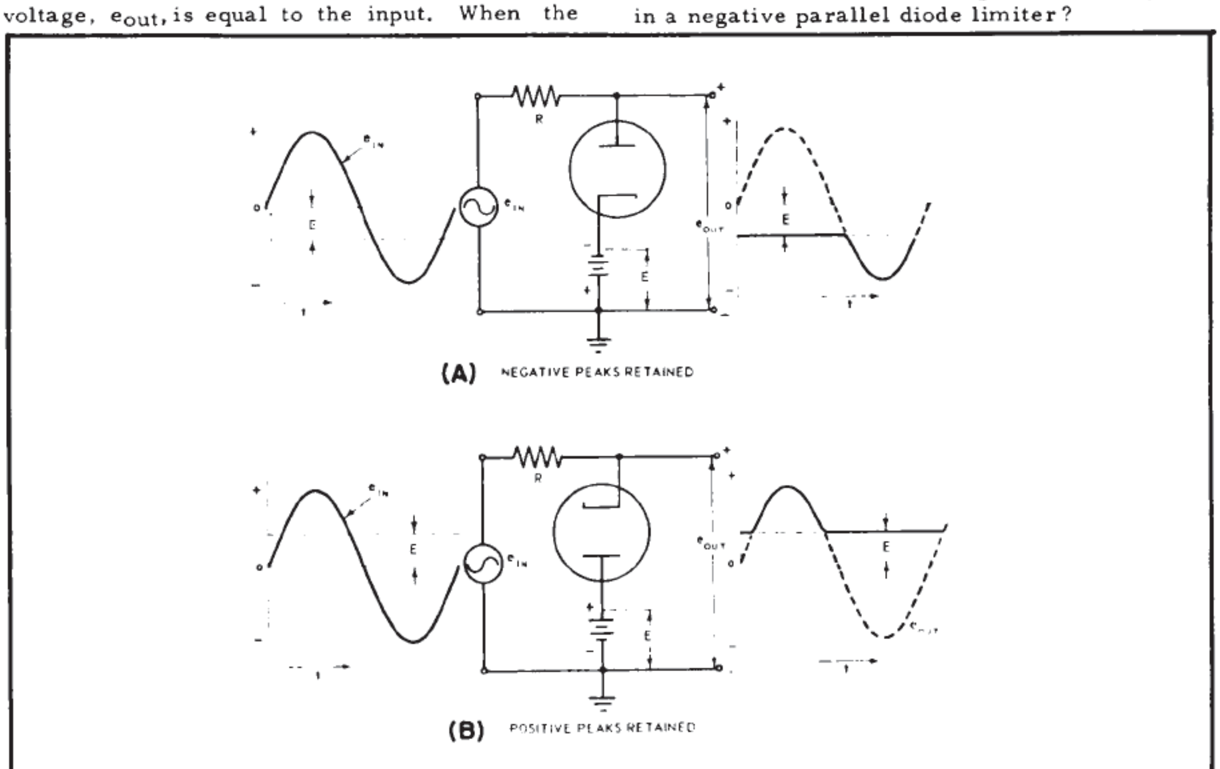

Figure 48-32 - Parallel diode limiters that pass peaks only.

Q27. What would be the positive and negative extremity of the output waveform of a parallel negative diode limiter with a positive 7 volts bias if the input varied between -15 volts and +15 volts?

Q28. What portion of an input waveform varying from -10 volts to +10 volts would be limited by a positive parallel diode limiter with a -2 volt negative bias?

48-14. Double Diode Limiters

Double-diode limiters are used to limit both positive and negative amplitude extremities. A circuit connected to provide this type of limiting is illustrated in Figure 48-33.

Diode V_1 conducts whenever the positive-going input signal exceeds E_1, thus limiting the positive output to the value of E_1. This results from the fact that V_1, in effect, connects the output terminals across E_1; V_2 is, of course, non-conducting, or an open circuit, during this time. The difference between e_{in} and E_1 appears as an i_R drop across R.

Diode V_2 conducts whenever the negative-going input signal exceeds E_2, thus limiting the output to the value of E_2 during the negative half cycle. During this time, the output terminals are connected, in effect, across E_2; and V_1 is, of course, an open circuit.

This circuit represents a simple method of producing a square-wave output from a sine wave input voltage.

Q29. How can the amount of limiting of either the positive or negative extremity be controlled when using a double-diode limiter?

48-15. Grid Limiting

The grid-cathode circuit of a triode, tetrode, or pentode may be employed as a limiter circuit in exactly the same way as the plate-cathode circuit of the diode limiter illustrated in the upper part of Figures 48-31 and 48-32. By inserting a series grid resistor in Figure 48-34A that is large compared with the grid-to-cathode resistance when grid current flows, essentially the entire positive half cycle of the input voltage is limited almost to zero. For example, the grid-to-cathode resistance may drop from an infinite value, when the grid potential is negative with respect to the cathode, to a value of the order of 1000 ohms when the grid becomes positive with respect to the cathode. If a one megohm resistor is placed in series with the grid, the voltage drop across the 1000 ohm R_{gk} is negligible compared with that which is developed across the one-megohm resistor by the flow of grid current.

The grid limiter circuit shown in Figure 48-34A is held normally at zero bias. During the positive portion of the input signal the grid attempts to swing positive. Grid current flows through R, developing an i_{gR} drop of such polarity as to oppose the positive input voltage. The larger R is with respect to R_{gk}, the smaller will be the relative voltage across R_{gk} when grid current flows. The drop across R may be considered as an automatic bias developed during that part of the input cycle when grid current flows.

Alternate circuits for limiting the positive peaks of the input voltage are shown in Figure 48-34B and C. In part B, the tube is biased by the negative grid potential, E, supplied to the grid. No grid current flows until e_{in} rises sufficiently to equal and effectively remove the biasing voltage, E. Any further rise of e_{in} drives the grid positive with respect to the cathode, and grid current through R limits the signal on the grid by virtue of the voltage drop across R.

In Figure 48-34C, bias is developed between grid and cathode by the flow of plate current through R_k. Any positive signal, e_{in}, must drive the grid positive by an amount equal to the value of E_k before the biasing effect of R_k is removed. A further rise of the input voltage produces grid current, and this results in the limiting of the voltage at the grid due to the value, E_k, and holds the voltage at this level over the entire cycle.

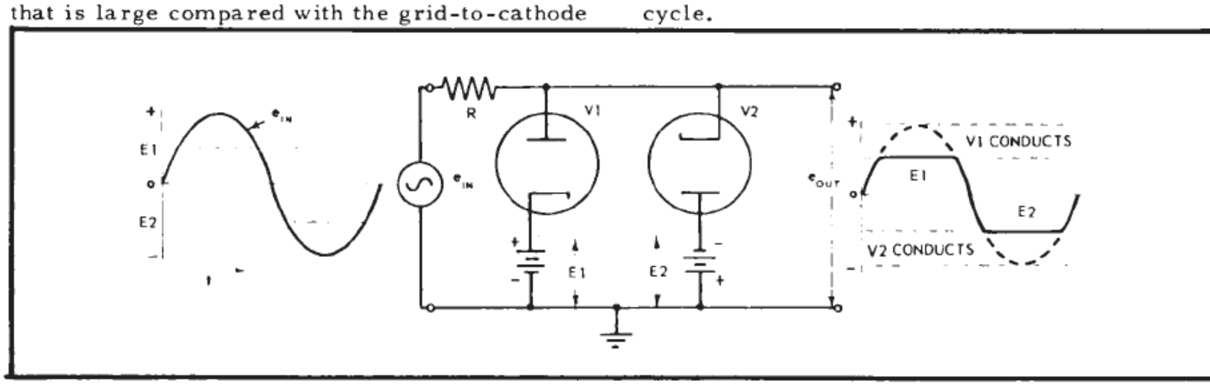

Figure 48-33 - Double-diode limiter.

A25. The portion that is more positive.

A26. The limiting action takes place when the input waveform goes negative.

A27. +7 volts to +15 volts.

A28. That portion between -2 volts and +10 volts would be limited.

A29. The amount of limiting can be controlled by changing the value of bias voltage.

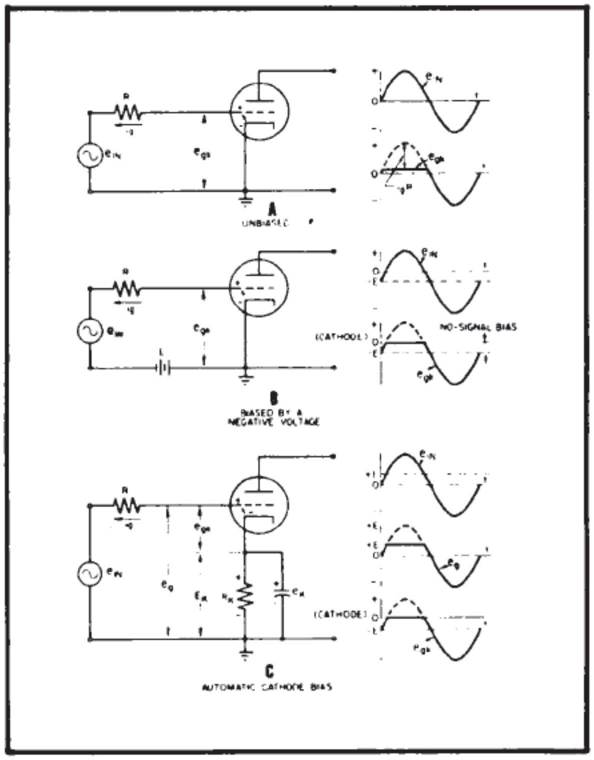

Figure 48-34 - Grid limiters.

It can be seen that whenever a series-limiting resistor is used in the grid circuit the grid cannot be driven to an appreciable positive voltage and, despite the positive amplitude of the input voltage, the maximum plate current which flows is that determined by the plate supply E_b and the resistance of the plate circuit at zero bias. Thus the minimum plate voltage is determined by the limiting action in the grid circuit. These plate current and plate voltage relationships are shown in Figure 48-35.

Q30. How can a grid limiter be identified?

Q31. What alternation of the grid waveform is limited?

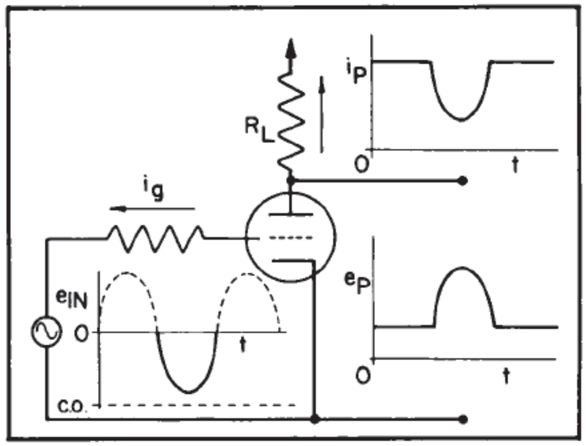

Figure 48-35 - Effect of grid limiting on plate current and plate voltage.

Q32. Which alternation of the plate waveform would be limited?

48-16. Saturation Limiting

The grid limiting resistor may be omitted, if the input signal comes from a low-impedance high power source, and limiting in the plate circuit may still be realized. This is due to the plate-circuit saturation and is usually referred to as SATURATION limiting. Plate-current saturation should not be confused with emission saturation since in tubes using oxide coated cathodes, there is no definite saturation value of emission current.

By using a large value of plate-load resistance, R_L, and a low plate-supply voltage E_b, saturation limiting may be produced by a relatively low amplitude of positive grid voltage. In any case, however, the plate current can never exceed the value E_{bb}/R_L. In an actual circuit, some positive voltage must remain on this plate to attract electrons from the cathode, and the saturation plate current never quite reaches E_{bb}/R_L. In other words, there remains across the tube a low voltage drop when plate current is at saturation, since the plate-to-cathode resistance at saturation does not decrease to zero.

In Figure 48-36 the I_b vs. e_b characteristic of a triode,(A) is used to illustrate the effect of saturation limiting on the plate voltage. The input signal applied to the grid(B), which is normally at zero grid bias, is not of sufficient amplitude to drive the tube to cut-off on the negative swing; but causes the plate current to saturate on the positive swing. The dotted extension of the load line describes the tube during the positive alternation of the input cycle. The maximum plate current,(C), cannot exceed the

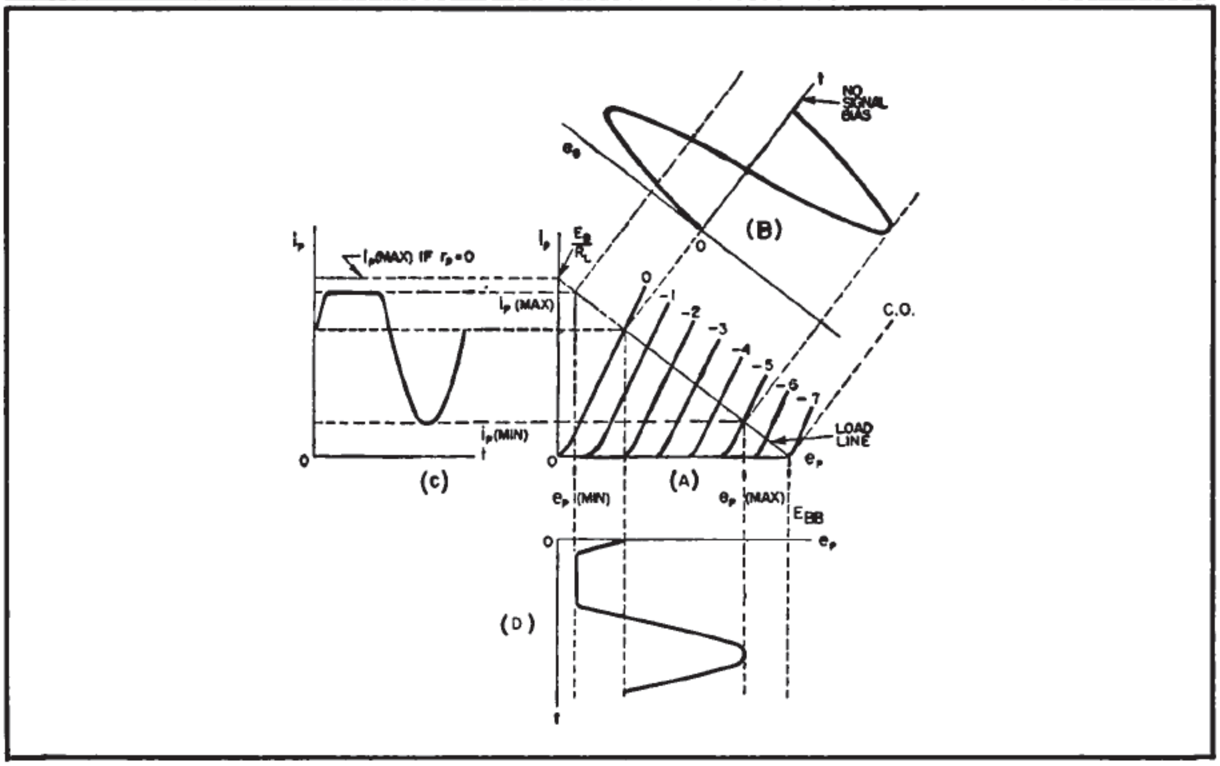

Figure 48-36 - Saturation limiting.

value E_b/R_L no matter how high the amplitude of the positive grid signal, and is actually slightly less because of the low-saturation plate resistance which remains in series with the load. The maximum plate current defines the lowest value to which the plate voltage can fall,(D). During the remaining portion of the input cycle

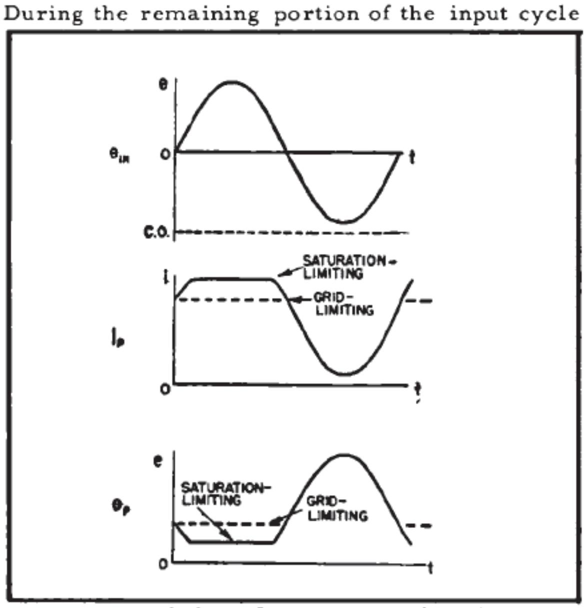

Figure 48-37 - Comparison of grid and saturation limiting.

the grid controls the flow of plate current which in turn determines the shape of the plate voltage waveform.

The results of saturation limiting are similar to those of grid limiting in that the negative-going portion of the plate voltage is affected. These are compared in Figure 48-37. Saturation limiting has the advantage of producing an output wave of greater amplitude, but it has the disadvantage of requiring considerably more power to drive the grid.

Q33. What are two circuit characteristics of a saturation limiter?

Q34. Which alternation of the plate waveform is limited by a saturation limiter?

48-17. Cut-off Limiting

Electron current through a vacuum tube can flow only from cathode to plate and not from plate to cathode. Therefore, plate current cannot become a negative value. When the grid is driven to cut-off, the plate current is decreased to zero and remains at zero during the time the grid is below cut-off. Since no current flows through the plate circuit when the tube is cut off, there is no voltage developed across the load resistance; and the plate is maintained at the full value of the plate supply voltage. Thus,

A30. A grid limiter can be identified by a large series resistor in the grid circuit.

A31. The positive alternation is limited.

A32. The negative alternation would appear to be limited.

A33. A large plate load resistor and a low B+.

A34. The negative alternation.

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a type of limiting is achieved in which the positive extreme of the plate waveform is flattened as a result of driving the grid beyond cut-off.

The cut-off voltage may be defined as the negative voltage, with respect to the cathode, to which the grid must be driven in order to prevent the flow of plate current. For any given type of tube this voltage level is a function of the plate supply voltage and in the case of triodes may be approximated by the expression:

$$E_{co} = E_b \qquad (48\text{-}1)$$

where E_b is the plate supply voltage and u is the amplification factor of the tube. This relation is not valid in the cases of tetrodes and pentrodes.

In Figure 48-38, the I_b vs. E_b characteristic of a triode is used to illustrate the limiting effect caused by driving the grid of an amplifier beyond cut-off. The grid is normally biased to -5 volts by the steady drop across R_k, A. The value of E_{bb} is such that the cut-off potential E_{co} is -7 volts. The maximum amplitude of the input voltage is 4 volts; thus the grid voltage, C, swings in a positive direction from -5 volts to -1 volt and in a negative direction from -5 volts to -9 volts. During the time that the grid voltage remains below cut-off, the plate current remains at zero and the plate voltage is held at the level of E_{bb}.

Q35. Which alternation of the plate waveform is clipped due to cut-off limiting?

48-18. Overdriven Amplifier (Combination Saturation and Cut-Off Limiting)

An amplifier circuit in which saturation-limiting is employed in conjunction with cut-off limiting to produce a rectangular wave from a sine wave is generally known as an OVERDRIVEN AMPLIFIER. The driving circuit for such an amplifier should have a relatively low-output impedance and be capable of delivering power, as considerable current is drawn during the positive swing of the grid. The value of the load resistor R_L, is made as large as practicable for the plate voltage supply available.

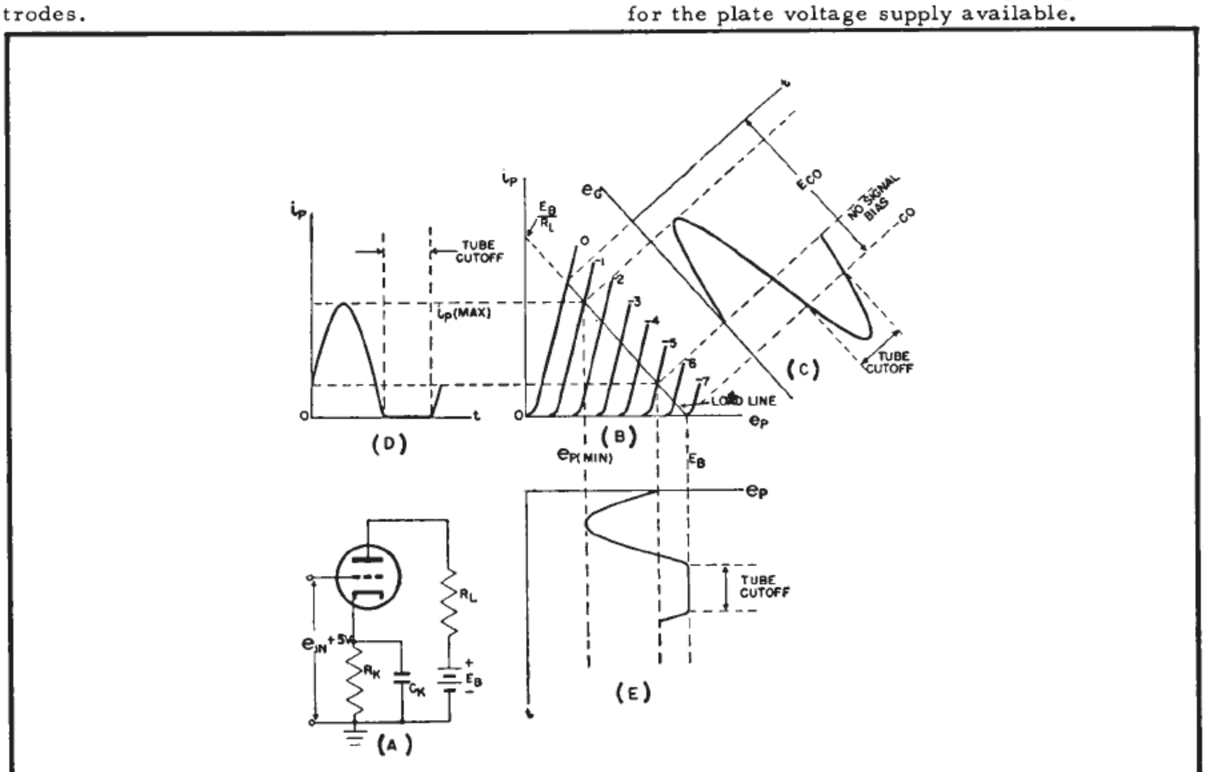

Figure 48-38 - Squaring top of plate voltage by cut-off limiting.

Figure 48-39 illustrates the grid-voltage, plate-current, and plate-voltage relationships as determined by the I_b vs. E_b characteristics and the circuit constants of the overdriven amplifier.

Q36. Name a primary requirement of an overdriven amplifier circuit as regards the amplitude of the input signal?

48-19. Limiter Applications

In radar work, very narrow pulses often are required to start oscillators into action, to force grids above cut-off so that the tube may conduct for a short period, or to modulate radio frequencies into brief pulses. Alternately positive and negative pulses, obtained in various ways, may be passed through a limiting circuit to obtain pulses which are either positive or negative with respect to a reference value. This reference level may be at zero voltage or any positive or negative potential. By alternate stages of amplification and limiting, the pulse may be narrowed to any width desired. A typical series of such actions is illustrated in Figure 48-40.

Limiting and differentiating circuits can be used in combination to change sine waves into square waves, and then to limit the peaks of the resultant waveform. A circuit for accomplishing this sequence of events is illustrated in Figure 48-41.

A sine wave is fed into the input. The series diode limiter removes the positive portion of the signal and passes the negative portion to the triode limiter. The diode can only conduct when its cathode is negative with respect to its plate- or, in this case, negative with respect to ground.

As the grid of the triode limiter becomes more negative, the plate current drops and plate voltage rises until the grid voltage reaches cut-off. The plate voltage remains at the applied voltage during the time the grid is held below cut-off. When the grid potential rises above cut-off, plate current increases, and the plate potential falls. Thus, a square wave is formed at the output of V_2.

If the grid of V_3 were disconnected, the square wave across the small time constant R_1C_1 would give a peaked wave with negative and positive pulses, or spikes across R_1. With the grid of V_3 connected, the larger part of the positive peak is clipper off because of grid current flow in V_3. The voltage applied to V_3 is therefore a series of negative pulses.

Except when negative pulses are applied to the grid of V_3, saturation current flows in the plate circuit, and the plate voltage is low. During the time negative pulses are applied to the grid of V_3, the voltage at its plate rises to the

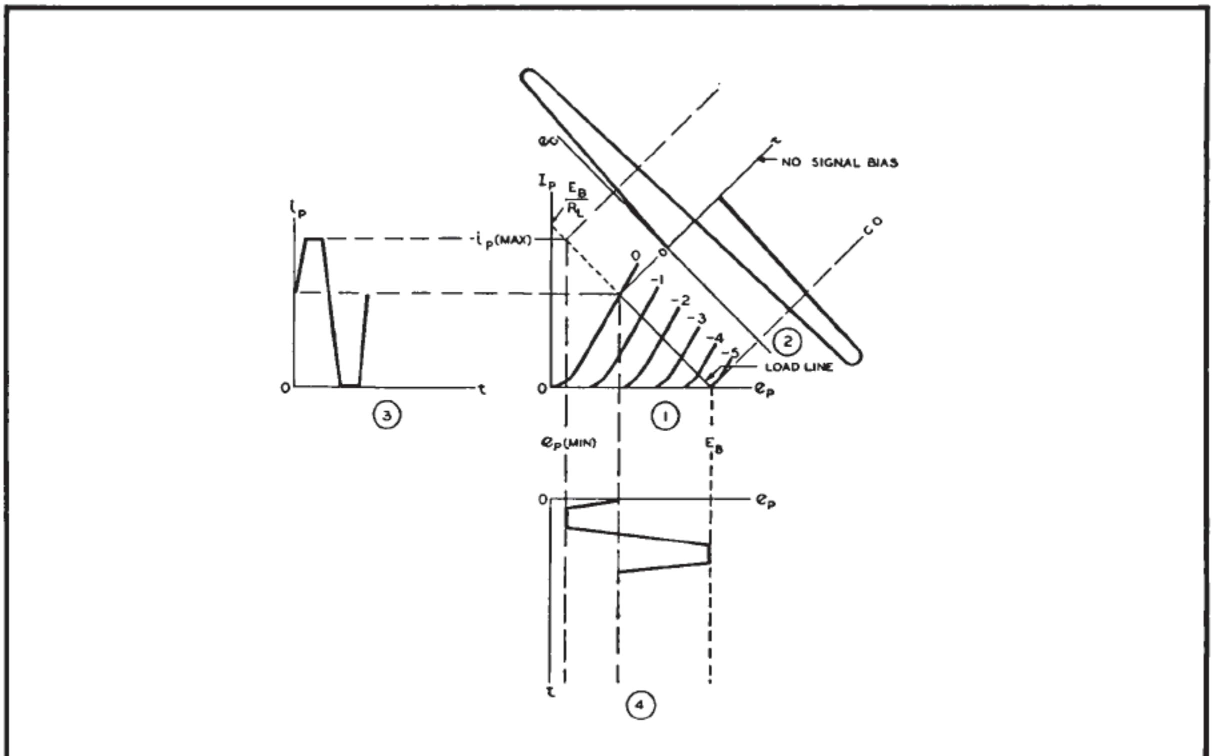

Figure 48-39 - Formation of square wave by saturation and cut-off limiting.

A35. The positive alternation.

A36. The input signal must be large in amplitude.

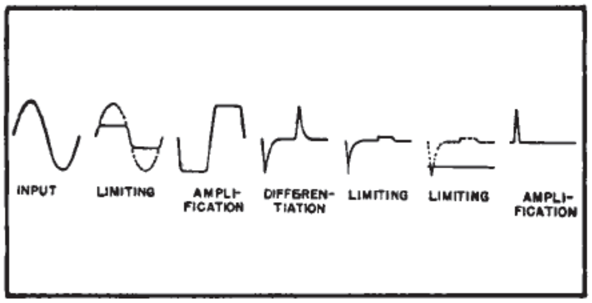

Figure 48-40 - Formation of narrow pulses by successive stages of special radar circuits.

supply voltage. The output is therefore a series of positive pulses.

Q37. How are limiting and differentiating circuits used to obtain a peaked wave from a sine wave?

48-20. The Purpose of Counting Circuits

A counting circuit receives uniform pulses representing units to be counted, and provides a voltage proportional to their frequency.

By slight modifications, the counting circuit is used in conjunction with a blocking oscillator to produce a trigger pulse which is a submultiple of the frequency of the pulses applied, thus acting as a frequency divider.

The pulses applied to the counting circuit must be of the same time duration if accurate frequency division is to be made. Counting circuits are ordinarily preceeded by shaping circuits and limiting circuits to insure uniformity of amplitude and width. Under these conditions, the pulse-repetition-frequency constitutes the only variable, and frequency variations may be measured.

Q38. Name a common application of counting circuits.

48-21. Positive Counters

Positive pulses, which may vary only in their recurrence frequency, are applied to the input of the positive counter shown in Figure 48-42. The charge on the coupling capacitor, C_1, cannot change instantaneously as the positive leading edge is applied; so the plate of V_2 becomes positive and the diode conducts. A charging current flows through R_1 during the pulse time and a small charge is developed on C_1. Between pulses V_2 cannot conduct, as its plate is negative with respect to its cathode. However, V_1 conducts, discharging the small charge from the capacitor, which would otherwise build up during each succeeding positive pulse, eventually rendering the circuit insensitive to the applied pulses.

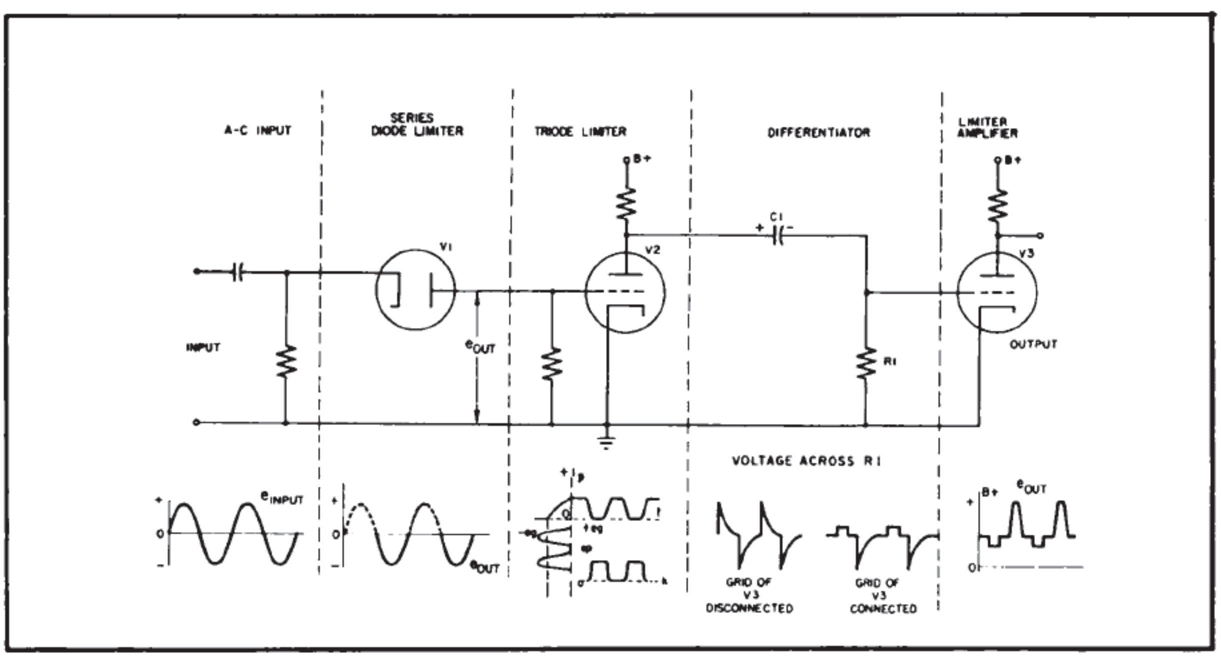

Figure 48-41 - A method of squaring and peaking a sine waveform.

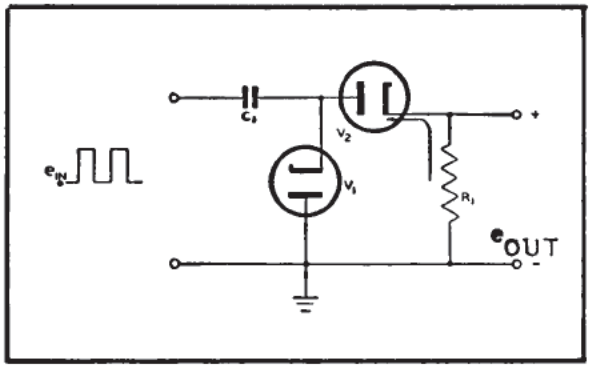

Figure 48-42 - Positive counting circuit.

It is apparent in Figure 48-42 that since a certain amount of current flows through R_1 each time a pulse is applied, an average current flows which increases as the pulse recurrence frequency increases and decreases as this frequency decreases. The IR drop developed across R_1 can be used to control a succeeding stage as illustrated in Figure 48-43. The filter in the grid circuit of V_3 aids in obtaining smooth operation by removing too rapid changes in voltage developed across R_1. The voltage at the grid of V_3 varies with changes in the pulse frequency and produces variations in the plate current of V_3. A milliammeter is placed in series with the plate circuit so that changes in the average plate current are indicated as a measure of variations in the recurrence frequency of the input pulses. This circuit could be made to count negative pulses if V_1 and V_2 were reversed.

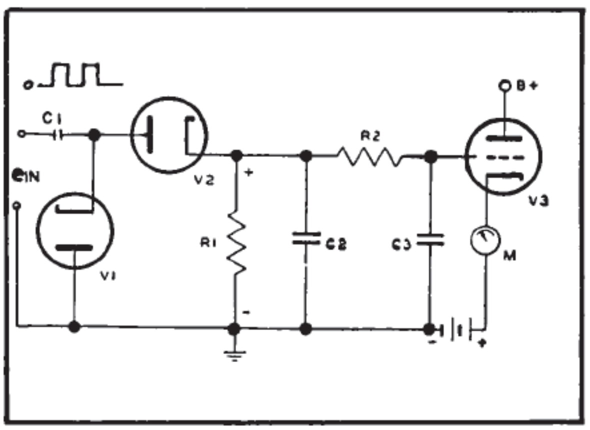

Figure 48-43 - Circuit controlled by a positive counter.

Q39. What determines the magnitude of the voltage on the control grid of V_3 in Figure 48-43?

Q40. What is the purpose of V_1?

48-22. Step-by-step Counting

It is often desirable to have a counting circuit that will count a specific number of pulses and then trigger another circuit, similar to the positive counting circuit in Figure 48-42.

For step counting, the load resistor of the positive counting circuit is replaced by a capacitor, C_2. This capacity is relatively large in comparison to the capacity of C_1. Each time V_2 conducts, the charge on C_2 is increased slightly as shown in Figure 48-44. The steps are not the same height, and they decrease in height exponentially with time as the voltage across C_2 approaches the final value, as shown in Figure 48-46.

As long as there is no discharge path for C_2, the voltage across its terminals increase with each successive step until it is equal in amplitude to the applied pulse. When this condition is reached, V_2 will no longer conduct because its plate and cathode are at the same potential.

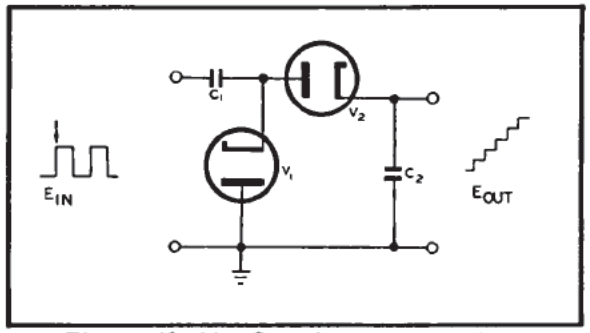

Figure 48-44 - Step-by-step counting.

The voltage across C_2 might be applied to a grid-controlled thyratron to cause the tube to conduct (fire) when the required number of pulses has been counted. The firing of the thyratron would discharge C_2, and the counting cycle would start all over again.

The circuit in Figure 48-45 may be used as a frequency divider. When used in this manner, V_3 is used as a single-swing blocking oscillator that is triggered when the voltage across C_2 becomes great enough to cause the tube to conduct. At other times, the tube is cut off by the bias voltage developed in the section of R that is between ground and the slider.

In operation, as soon as the charge on C_2 is great enough to overcome the bias voltage, the grid of V_3 swings positive with respect to its cathode, and the heavy grid current quickly discharges C_2. A positive pulse at the output will appear as a submultiple of the input PRF.

The submultiple number is determined by the setting of R, which sets the bias voltage of V_3 and thereby selects the number of pulses that must be applied to the input before V_3 will conduct. For example, a PRF of 1000 cps may be

A37. The limiter changes the sine wave to a rectangular wave and the differentiator changes the rectangular wave to a peaked wave.

A38. Frequency counters or frequency dividers.

A39. The frequency of e_{in}.

A40. To provide a quick discharge path for C_1 when the positive pulse is removed from the input.

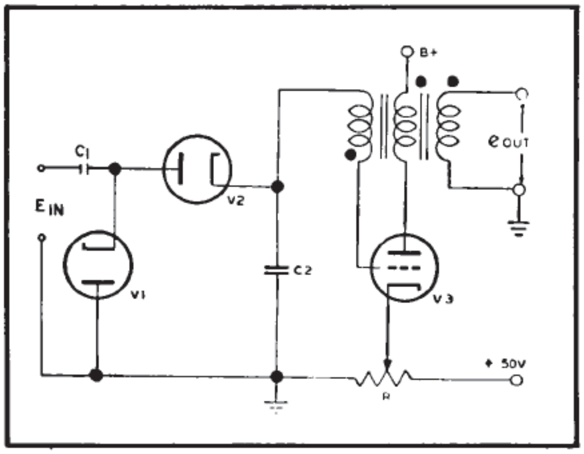

Figure 48-45 - Blocking oscillator triggered by counter circuit.

fed to the input of the counting circuit. The bias on V_3 is adjusted so that the voltage built up on C_2 will overcome the bias voltage every fourth step (as shown in Figure 48-45). Therefore, the rise in voltage on the capacitor triggers the oscillator and the current flow through the oscillator then discharges the capacitor. The oscillator output pulse frequency would then be one-fourth the input frequency, or 250 cps.

When using step-by-step counting circuits, the amplitude of e_{in} becomes significant and must remain constant. This is because any variation of e_{in} amplitude could cause an inaccuracy in counting which is based on a given output level.

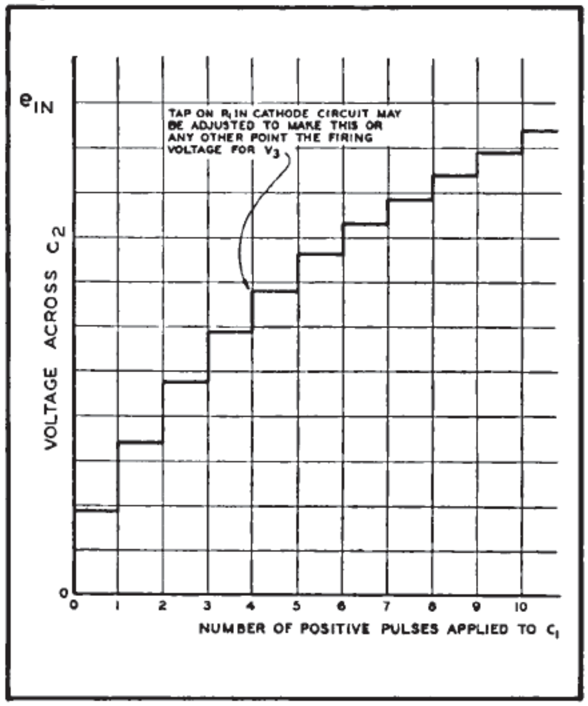

Figure 48-46 - Step voltage developed across C_2.

Q41. What is the basic difference between a simple positive counter and a step counter?

EXERCISE 48

1. Define negative clamping.
2. What part of the waveform is limited by a positive clamper?
3. On which alternation of the input waveform would the diode in a positive clamper conduct?
4. When will the sum of the capacitor voltage and input voltage in a positive clamper equal the output voltage?
5. A positive diode clamper with a +15 volt bias has an input varying between -20 volts and +40 volts, what would be the upper and lower extremities of the output waveform?
6. A positive clamper with a -20 volts bias has an input waveform varying between -100 and +100 volts. To what reference would the most negative extremity of the waveform be clamped?
7. In the example of question 6, what would be the upper and lower extremities of the output waveform?
8. On which alternation of the input waveform would the diode in a negative diode clamper be non-conducting?
9. A negative diode clamper with a negative bias of 15 volts has an input waveform varying between +90 and +110 volts. To what reference would the most positive extremiety of the output waveform be clamped?
10. In the example in question 10, what would be the upper and lower extremities of the output waveforms?
11. Why is a resistor used in the diode clamper circuit?
12. What would happen to the output waveform of a diode clamper if the resistor in the clamper circuit became very low in value?
13. On which alternation of the input waveform does the capacitor charge in grid clamping?
14. Grid clamping positions which extremity of the waveform to the reference?
15. Where are clamping circuits often used?
16. What are other names for clampers?
17. What is the function of limiters?
18. Does a series diode limiter perform when the tube is cut off?
19. Do parallel diode limiters operate when the tube is cut off? Explain.
20. On which alternation of the input waveform would the diode in a positive series diode limiter conduct?
21. On which alternation of the input waveform would the diode in a negative parallel diode limiter conduct?
22. A positive parallel diode limiter with a -7 volts bias has an input varying between -10 volts and +10 volts. What part of this waveform would be seen in the output?
23. What portion of an input waveform varying between -20 volts and +20 volts would be limited by a negative parallel diode limiter with -12 volts bias?
24. A double diode limiter with no bias would limit what portion of an input varying between -5 volts and +5 volts?
25. A triode with a large series resistor in the grid circuit indicates what type of limiting?
26. Which alternation of the plate waveform would be limited by grid limiting?
27. Which alternation of the plate waveform would be limited by saturation limiting?
28. How can a normal triode amplifier circuit be used to obtain saturation limiting?
29. Which alternation of the grid waveform is clipped by grid limiting?
30. What alternation of the plate waveform is clipped by cut-off limiting?
31. Which alternation of the grid waveform is clipped due to cut-off limiting?
32. What type of limiting is accomplished by overdriving an amplifier with a large amplitude sine wave input?
33. If a sharp spike output was desired at every instant a sine wave exceeded the zero reference, what combination of circuits could be used?
34. Name a principle variable as far as the input pulses are concerned when they are fed into a positive counter?
35. What can be accomplished by a step counter in conjunction with a driven blocking oscillator?

A41. The load resistor in a positive counter when replaced by a capacitor converts the circuit into a step counter.

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